20

SYSTEMS, SCIENCE AND SOFTWARE

3SR-405 —A

THE ZAP LASER ANALYSIS PROGRAM

Report Prepared By:

J.H. Alexander
M. Troost
J.E. Welch

This effort was sponsored by the
Advanced Research Projects Agency
ARPA Order No. 660
Contract No. N00014-70-C-0341

June 1971

P. O. BOX 1620. LA JOLLA. CALIFORNIA 92037. TELEPHONE (714) 453-0060

346

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Systems, Science and Software P.O. Box 1620 La Jolla, California	2a. REPORT SECURITY CLASSIFICATION Unclassified
	2b. GROUP

3. REPORT TITLE
THE ZAP LASER ANALYSIS PROGRAM

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Final Report

5. AUTHOR(S) (First name, middle initial, last name)
James H. Alexander
M. Troost
J.E. Welch

6. REPORT DATE June 1971	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS 0
8a. CONTRACT OR GRANT NO. ARPA Order No. 660	9a. ORIGINATOR'S REPORT NUMBER(S) 3SR-405 — A	
b. PROJECT NO.		
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
d.		

10. DISTRIBUTION STATEMENT

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Advanced Research Projects Agency

13. ABSTRACT

This report presents a detailed description of the ZAP computer program. It is used to determine the distribution of energy deposition within a laser assembly. The program is written in FORTRAN IV. The calculation uses ray tracing and Monte Carlo techniques to obtain a solution. The program is applicable to a wide range of geometries and a spectrum of wave lengths.

DD FORM 1 NOV 65 1473

Security Classification

SYSTEMS, SCIENCE AND SOFTWARE

3SR-405-A

THE ZAP LASER ANALYSIS PROGRAM

by

J.H. Alexander
M. Troost
J.E. Welch

Final Report

Principal Investigator: Dr. Marius Troost (714) 453-0060
Project Scientist: Mr. C. W. Hartley (ONR)

Sponsored by
Advanced Research Projects Agency
ARPA Order No. 660

Program Code Number: 6 23 01 D
Contract No. N00014-70-C-0341
Effective Date of Contract: 1 May 1970
Contract Expiration Date: 31 December 1970
Amount of Contract: $44,000

June 1971

P.O. BOX 1620, LA JOLLA, CALIFORNIA 92037, TELEPHONE (714) 453-0060

3SR-405-A
[redacted]

PREFACE

The ZAP laser analysis program was written for the Naval Research Laboratory, Washington, D.C., under contract N00014-70-C-0341. The Principal Investigator was Dr. M. Troost. The code was programmed and debugged by J.E. Welch. Dr. J.H. Alexander contributed strongly to the geometrical analysis, in particular the Helix. Dr. A.G. Petschek defined the statistical analysis. Dr. J. Trenholme of NRL made many worthwhile suggestions for improving the program and contributed the second sample problem. The excellent cooperation by NRL personnel throughout the contract period contributed significantly to the success of this contract.

ABSTRACT

This report presents a detailed description of the ZAP computer program. It is used to determine the distribution of energy deposition within a laser assembly. The program is written in FORTRAN IV. The calculation uses ray tracing and Monte Carlo techniques to obtain a solution. The program is applicable to a wide range of geometries and a spectrum of wave lengths.

TABLE OF CONTENTS

TABLE OF CONTENTS, Contd.

TABLE OF CONTENTS, Contd.

TABLE OF CONTENTS, Contd.

TABLE OF CONTENTS, Contd.

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS, Contd.

1. METHODS USED

1.1 INTRODUCTION

Several methods might be employed to calculate the distribution of the energy deposition within a laser assembly. Analytical calculations are impossible due to the complexity of the geometry. Numerical solutions of the relevant wave equations should be possible, but the computer time cost for three-dimensional calculations is prohibitive. Ray tracing, which is frequently used in optical problems, seems to be the most practical method available.

1.2 RAY TRACING

In ray tracing, rays may be selected systematically or at random. In simple geometries, systematic selection of rays is advantageous, as only a few are needed for a good sample. In complicated 3-dimensional geometries, the number of rays required for an adequate systematic sampling becomes prohibitively large, and randomly selected rays from known distributions will give more reliable results for the same amount of computer time. As many laser designs are of considerable complexity, the ZAP program uses randomly selected rays from specified distributions. Each ray is defined by the three directional cosines, the coordinates of the starting point, and an intensity distribution as a function of wavelength.

A problem for any method of ray tracing in a design with a large amount of internal reflection and no black absorbers, is to decide when to stop following a particular ray. As each ray loses its energy very gradually via partial absorption, it is impractical to follow the ray until it is completely absorbed; without a black absorber this would take a very large number of reflections. If a ray is ignored only after its energy falls below a negligible level (e.g., 1% of its original strength), the paradoxical situation exists where most of the tracing effort is used for rays that contribute very little to the final result. If, on the other hand, each ray is cut off when its energy is still significant (e.g., 25% of its original strength), larger errors will be made. A method is needed that does not ignore weak rays, but that does not waste too much effort on them.

1.3 MONTE CARLO AND RUSSIAN ROULETTE

By randomly selecting the rays to be traced, the problem is transformed into one that can be solved by Monte Carlo methods. A technique frequently used in Monte Carlo solutions is the Russian Roulette Technique. This technique allows each ray to be cut off while its energy is still significant without ignoring the weak rays. Basically this method involves statistically eliminating some weak rays, while strengthening other weak rays for further tracing. In practice, the Russian Roulette method works as follows.

A ray is followed until its intensity falls below a certain predetermined level (e.g., 50% of original intensity). At that point, it is decided randomly whether this ray will survive. If it dies, it is ignored and no record is kept. If it survives, its intensity is multiplied by a factor which is the inverse of the probability of survival in the random test. The intensity of the surviving ray is therefore always relatively high (e.g., above 50% of the original intensity). As each ray may several times pass through this procedure before being killed, even very weak rays are statistically represented in the sample. Partial reflections may be treated by creating a new ray of appropriate intensity. A pass through the Russian Roulette routine will then decide whether the new ray survives and with what intensity.

Energy deposition is determined by calculating the exponential attenuation along the path of a ray. The deposition is assigned to the segment through which the ray passed. The intensity is checked at every intersection of the ray with a boundary, and a game of Russian Roulette is played when necessary. Eventually each ray will therefore be killed in a game of Russian Roulette.

1.4 ACCURACY

The accuracy of the energy absorbed in the various regions of the system is dependent on the number of rays traced. Several runs may be necessary to determine the number of rays needed for the accuracy required.

1.5 MULTIPLE WAVELENGTHS

Multiple wavelengths are handled in the ZAP program by assigning intensities for each wavelength to a single ray. For this technique to be applied it must be assumed that the angle of refraction at a material interface is independent of wavelength, which is an approximation. The absorption coefficients and the percent reflected may vary with wavelength.

As the ray is traced through the system, the amount absorbed for different wavelengths varies. Therefore some wavelengths will be destroyed by Russian Roulette while other wavelengths survive. The ray is traced until all wavelengths have lost their intensity either by absorption or by Russian Roulette.

The energy deposited in a material by a given ray is the sum of the contributions of the various wavelengths.

1.6 GEOMETRY SPECIFICATIONS

A flexible method for describing the geometry of the system has been developed which allows simple input and fast computation. At the same time, it allows for great generality in geometrical configuration.

A problem common to many Monte Carlo codes is their extreme slowness when applied to complicated geometries. This slowness is caused by the need to check for possible intersections with all possible boundaries. The running time thus becomes roughly proportional to the number of boundaries in the system. It becomes quickly evident that some technique is needed which eliminates the necessity for checking all boundaries for each intersection.

One possible solution to this problem is to divide space into subregions and to check only for possible intersections with those boundaries that exist in the subregion and with the boundaries of the subregion itself. Some modern Monte Carlo codes use this method, but they are often inconvenient to use because of the cumbersome geometrical definitions required for each subregion.

Systems, Science and Software (S^3) has developed a method which uses the subdivision method recursively. The geometry is specified by a greatly simplified geometrical input, as the subregions used are the natural geometrical shapes of the system.

1.7 SEGMENTS

Each part of space in the problem to be studied is divided into one or more segments. A single piece of material may belong to several segments or a segment may contain several materials in the form of subsegments. Two kinds of segments are defined: Mother segments and Daughter segments.

The Mother segments act as subregions and the Daughter segments lie within Mother segments. When a photon lies in a particular Mother segment, only the intersections with boundaries of that Mother segment and its Daughter segments need to be checked. The boundaries of the Mother segment shield the photon therefore from the details in the space outside the Mother segment.

It frequently is also desirable to shield the photon from details in certain areas within the Mother segment. This may be done by enclosing these details in a Daughter segment and declaring this Daughter segment to be a Mother segment at a lower level. We now have a recursive definition of Mother and Daughter segments, where any Mother segment may be a Daughter segment of a higher level Mother and any Daughter segment may be a lower level Mother segment.

The geometry of the complete system fits into one Mother segment. This Mother segment usually will have several Daughter segments that are Mother segments in turn.

This recursive subdivision may be continued to any desired depth. Any Daughter segment, that is not a Mother segment, must consist of a homogeneous material.

A Mother segment is a segment that is partially or completely filled by one or more Daughter segments. That part of space within a Mother segment that is not occupied by Daughter segments has the material properties of the Mother segment. The volume of the Mother segment is the volume of the space within the Mother segment that is not occupied by Daughter segments.

Whenever possible, Mother segments should have simple shapes, e.g., rectangular parallelepiped, cylinder, sphere. A simple shape allows an efficient check for boundary crossings and reduces computer time. However, in principle a

Mother segment may have any shape, even though that may be expensive in computer time.

Although the possible number of Daughter segments within a Mother segment is unlimited, in practice this number should be quite low (e.g., below 5) to reduce the number of boundary crossing checks. After all, the Mother segment was introduced to reduce the number of potential boundary crossings.

A Daughter segment must lie completely within its Mother segment. Each Daughter segment is therefore associated with only one Mother segment. Each Daughter segment may in turn be a lower level Mother segment.

For each Mother segment, all of the external boundaries must be specified. Boundaries of Daughters need not be specified for the Mother. For each Daughter segment, all of the confining boundaries must be specified.

In specifying the boundaries of a given segment, it is necessary to know on which side of the boundary the segment lies. For a plane, one must specify if the segment is on the origin or non-origin side of the plane. This is accomplished by specifying a positive boundary number for the origin side and a negative boundary number to indicate that the segment is on the non-origin side. For curved surfaces, a positive boundary number means that the segment is inside the surface and a negative boundary number indicates that the segment lies outside the boundary.

1.8 SURFACE DEFINITIONS

The geometric surfaces of the system are defined conveniently for vector calculations. In theory, any mathematically definable geometric shape can be used with the ZAP program by adding the appropriate subroutines to the computer code. The definitions for the geometry types of most general interest are summarized below:

1.8.1 Plane

A plane is defined by the directional cosines of the normal to the plane and the coordinate of a point which lies on the plane (Fig. 2.1).

1.8.2 Cylinder

A cylindrical surface is defined by the directional cosines of the cylindrical axis, the coordinates of a point on the axis, and the radius (Fig. 2.2).

1.8.3 Conic Cylinder

A conic cylinder whose major axis is perpendicular to the Z axis (Fig. 2.4) is defined by the directional cosines of the major axis of the conic, the X-Y coordinates of the focus, and the X-Y coordinates of two points on the conic surface. The two points must not be symmetric relative to the axis, although one of them may lie on the axis.

Whether the conic represents a parabola, hyperbola, or ellipse is defined by the value of the eccentricity, which can be calculated from the data provided.

parabola:	$e_k = 1$
hyperbola:	$e_k > 1$
ellipse:	$e_k < 1$

1.8.4 Sphere

A sphere is defined by the coordinates of the center of the sphere and the radius (Fig. 2.3).

1.8.5 Half-cone

A half-cone whose axis of symmetry is parallel to the Z axis (Fig. 2.5) is defined by the coordinates of the vertex, and coordinates of a point on the surface of the half cone.

1.8.6 Paraboloid of Revolution

A paraboloid of revolution whose axis of symmetry is parallel to the Z axis (Fig. 2.7) may be defined by specifying the coordinates of the vertex and the Z coordinate of the focus.

1.8.7 Prolate Elipsoid of Revolution

A prolate ellipsoid of revolution whose axis of symmetry is parallel to the Z axis (Fig. 2.6) is defined by the coordinates of one of the vertices, the Z coordinate of the focus nearest the chosen vertex, and the coordinates of a point on the surface.

1.8.8 Hyperboloid of Revolution

One sheet of a hyperboloid of revolution whose axis of symmetry is parallel to the Z axis (Fig. 2.8) is defined by the vertex of the sheet of interest, the Z coordinate of the focus of the sheet of interest and the coodinates of a point on the surface. This point may lie on either sheet.

1.8.9 Helical Tube

A helical tube must have its major axis parallel to the Z axis. A point on the axis is chosen such that the perpendicular from the point to the centerline of the helical tube lies along the X axis and points from the point to the centerline in the positive X direction. The perpendicular distance from the axis to the centerline is specified and the radius of the tube must be specified. The only other parameter required is proportional to the distance between successive coils.

1.8.10 Boundary Intersections

In order to determine which boundary is next intersected by a ray, it is necessary to calculate along the direction of the ray the distance to all pertinent boundaries and choose the boundary which gives the smallest positive distance. Because of the segmentation, it is not necessary to calculate the distance to all of the boundaries in the system, but merely to a subset of these boundaries defined by the current Mother and its daughters. This is accomplished as follows:

1. When a photon is inside a Daughter segment, the following boundaries should be checked:
    a. The boundaries of the current Daughter segment.
    b. The boundaries of the Mother segment.
2. When a photon is inside a Mother segment, but not inside any of its Daughter segments, the following boundaries should be checked:
    a. The boundaries of all Daughter segments in this Mother segment.
    b. The boundaries of the Mother segment.

1.9 NEW SEGMENT DETERMINATION

After a photon has crossed a boundary, the segment containing the photon must be determined. This requires checking each boundary of the segment to determine if the photon lies on the desired side of the boundary. If the photon lies on the wrong side of any boundary of a segment, it is not in that segment. This search is conducted as follows:

1. Is the photon still in the Mother Segment? If the answer is yes,

2. Check each Daughter segment until one is found that contains the photon.

If the photon does not lie in any of the Daughter segments, it lies by definition in the Mother segment of space. If the photon lies within a Daughter segment, a check must be made to see if this Daughter segment is a Mother segment at a lower level. If such is the case, the procedure must be repeated starting at (2) for this new Mother segment.

If the photon lies outside the current Mother segment, the procedure should be repeated starting with (1) for the next higher level Mother segment.

The search thus continues until the final segment containing the photon has been found. This might involve climbing several Mother levels and then descending several Mother levels. The algorithm is written recursively, and is not concerned with the absolute Mother level. When a photon is found outside the highest level Mother, which defines the boundaries of the complete geometry, an error stop will occur.

1.10 NORMAL TO THE SURFACE

In order to calculate the angle of incidence and the angle of refraction for a ray intersecting a surface, it is necessary to determine the directional cosines of the normal to that surface at the point of intersection. The equations used to calculate the directional cosines of the normal depend on the geometry type of the surface.

1.11 ANGLE OF REFLECTION

When a ray intersects a surface, part or all of the ray reflects off the surface at some angle which must be determined. In the case of specular reflection, this angle is the same as the angle of incidence, but in a different direction. With a diffuse or Lambertian surface, the ray reflects with an angle chosen at random from a known distribution.

1.12 ANGLE OF REFRACTION

When part or all of a ray is transmitted through a real surface, the transmitted ray may be refracted. The directional cosines of the refracted ray must then be calculated.

1.13 PERCENT OF REFLECTION

Each boundary is assigned a reflection type which defines the method used to determine the percent of the ray that is reflected. Each reflection type is designed to handle a particular type of boundary that might be necessary in setting up a geometrical system. All reflections are assumed to be specular with the exception of diffuse reflection. The following types of reflection are currently in the ZAP program.

1.13.1 Fresnel's Reflection for Dielectrics

The surface of laser rods and lamps or any other type of glass component will generally be represented by Fresnel's reflection.

1.13.2 No Reflection

A non-reflective or dummy boundary is used primarily for segmentation purposes. The material should be the same on each side of the boundary. Hence there is no refraction either.

1.13.3 Total Reflection

Total reflection boundaries are used primarily for boundaries of symmetry, but can also be used for other purposes where one wishes the impending ray to be totally reflected.

1.13.4 Constant Reflection

Rays are reflected with constant percent of the intensity going with the reflected ray regardless of material properties or the angle of incidence.

1.13.5 Table Reflection

Rays are reflected by a percent which is dependent on the angle of incidence. A table is provided which gives the percent as a function of angle, and interpolation in the table gives the percent to be used.

1.13.6 Function Reflection

Any number of functions might be used to give the percent of reflection. One of particular interest is

percent reflection = $1-A\cos^2\theta$

where

θ = angle of incidence

A = a coefficient between 0 and 1.

1.13.7 Diffusion Reflection

In the case of a diffuse surface (see angle of reflection), the percent to be reflected is considered to be a constant which may be chosen for the particular surface under consideration.

1.13.8 Wavelength Dependent Reflection

The percent of the ray to be reflected may be dependent only on the wavelength, or may be dependent on the wavelength and the angle of incidence.

1.14 SOURCE DEFINITION

1.14.1 Surface Source

One type of source that is available is a surface source for a cylinder whose axis is parallel to the Z axis. A random point is chosen on the surface of the cylinder, and a ray is started from that point. The direction of the ray is determined by a subroutine that is provided by the user. This subroutine provides an angle ∂ with the normal to the surface at the point, and an angle ϕ with the cylinder axis in the plane tangent to the point. The distribution of the rays is therefore under user control, and can be chosen to fit the model desired. From these two angles, the directional cosines of the ray can be calculated. An option provides for the rays to be directed outwards from the cylinder surface or inwards from the cylinder surface.

1.14.2 Volume Source

If desired, a volume source may be used. For a volume source, a starting point is chosen at random within the source segment. A direction is then chosen in such a way as to give isotropic emission. This is accomplished by choosing another random point within a unit sphere having the starting point as the center. These two points uniquely define the ray and the directional cosines are easily calculated.

More than one source may be included within a given system. For each source the number of rays to be created is input and an initial energy distribution for the desired wavelengths must be provided. This distribution may be read in from cards or may be input by providing a subroutine to produce the desired results.

1.15 ENERGY DEPOSITION

When a ray passes through an absorbing material, energy is deposited in the material for each of the wavelengths being considered. For each wavelength the ray intensity is decayed exponentially and the amount lost by the ray is deposited in the material through which the ray has passed. The amount lost by different wavelengths is dependent on the distance traveled and the absorption coefficient of the material for each wavelength. It is therefore necessary to provide an absorption distribution as a function of wavelength for each material.

1.16 LOGIC FLOW

The flow of logic using the ZAP program is as follows:

1. Generate a ray or continue with a leg of the previous ray.
2. Determine the number of the segment containing the ray.
3. Find the distance to the intersection point or points for each of the appropriate boundaries and choose the boundary with the smallest positive distance.
4. Deposit energy in the segment through which the ray has just passed.
5. Determine the segment number on the opposite side of the intersected boundary.
6. Find the normal to the surface at the point of intersection.
7. Calculate the angle of reflection, the angle of refraction and the percent of the ray to be reflected. Calculate the directional cosines of the reflected and transmitted rays.
8. Play Russian Roulette with each wavelength of the reflected and transmitted rays. If the wavelength survives, double its intensity. If it does not survive, zero its intensity. The same random number is used for each wavelength.

9. Determine if the transmitted ray still has live wavelengths. If it does, start again with step 3. If it does not, go back to step 1.

The above procedure is repeated until the desired number of rays have been traced to extinction. After all rays have been completed, the final segment and material results are printed, and the problem ends.

1.17 OTHER USES

The ZAP program is a technique for solving optics problems of many types. Although it was developed for the analysis of laser efficiency it is also a general optics program that may be applied to a wide range of problems.

An example of another use is in the area of designing reflectors for spotlights. The problem would be set up with a reflector and spherical light source within the reflector. At some desired distance in front of the reflector a black nonreflecting plane would be placed, and the material behind the plane would be divided up into segments. The final absorbed energy distribution in the target segments would give a very effective measure of the focusing ability of the reflector. Many optics problems involving light sources and eventual light absorption may be solved with the ZAP program.

2. THE PROGRAM

2.1 PROGRAMMING PHILOSOPHY

The ZAP program was developed on the UNIVAC 1108 and was written in basic FORTRAN IV and is as machine independent as is possible. A version exists for the CDC-3800.

Throughout the development of the program, every effort was made to make the program as general as possible. In those cases that require special geometric shapes not available in the present code, new geometry routines may be incorporated in the program by adding the name of the geometry to a table and writing four subroutines to handle the tasks required for each geometric shape. Likewise, new types of reflection or ray creation may be added in the same manner.

As far as is possible, each subroutine or function in the code handles a given task without regard to what has happened before the routine was called. In that way these routines may be called from various sections of the program to perform the same task for different purposes. Obviously this is not always possible, but a definite effort was made in that direction whenever possible. One obvious drawback to this is the resulting large number of subroutines, some of which are so short as to be almost ridiculous. However, it was felt that the advantages far outweigh the disadvantages. Changing the way a particular task is performed usually means replacing a small subroutine rather than making changes to a large subroutine.

The remainder of this section presents the mathematical equations used for source generation, reflection and refraction. The equations used for each of the allowable geometries are given next.

2.2 SOURCES

After a ray has been absorbed or eliminated by Russian Roulette, a new ray must be created. The intensity distribution of the new ray is acquired from a table (ESOR(N,F)) that was set up at the beginning of the run, where N = the source number and F is the wave length index.

The position and direction of the new ray depends on the type of source being used.

Let

$$\left.\begin{array}{l} x_i \\ y_i \\ z_i \end{array}\right\} = \text{the coordinates of the starting point of the ray.}$$

$$\left.\begin{array}{l} \alpha_i \\ \beta_i \\ \gamma_i \end{array}\right\} = \text{the directional cosines of the ray.}$$

2.2.1 Surface Source

For a surface source the new ray is created at the surface of a cylinder whose axis is parallel to the Z axis. The ray may be directed either inwards or outwards from the surface.

Let

θ_1	=	an angle in the plane perpendicular to the cylinder axis
θ	=	the angle of the ray with the normal to the surface
ϕ	=	an angle with the cylinder axis in the plane perpendicular to the normal
ZMIN	=	minimum z value for starting point of ray
Δz	=	istance along the z axis for starting point of ray
x_k, y_k	=	coordinate of a point on the cylinder axis.
RAND	=	a random number between 0 and 1.

Choose a random angle θ_1 $\quad 0 \le \theta_1 \le 2\Pi$

$$x_i = x_k + \left(d_k \pm \varepsilon\right) * \cos \theta_1$$

$$y_i = y_k + \left(d_k \pm \varepsilon\right) * \sin \theta_1$$

$$z_i = \text{ZMIN} + \Delta z * \text{RAND}.$$

In order to calculate the directional cosines of the ray it is first necessary to find the directional cosines of the normal to the surface at the point (x_i, y_i, z_i).

$$\left.\begin{matrix}\alpha_n \\ \beta_n \\ \gamma_n\end{matrix}\right\} = \text{directional cosines of the normal to the surface at the starting point}$$

The angles θ and ϕ are determined by a special subroutine. This subroutine must be provided by the user, and will be written to give the desired distribution of rays.

$$0 \leq \theta \leq \frac{\Pi}{2}$$

$$0 \leq \phi \leq 2\Pi$$

then

$$\alpha_i = \alpha_n \cos\theta + \beta_n \sin\theta \sin\phi$$

$$\beta_i = \beta_n \cos\theta - \alpha_n \sin\theta \sin\phi$$

$$\gamma_i = \cos\phi \sin\theta$$

If it is desired for the ray to point inwards from the surface, the signs of its directional cosines $(\alpha_i, \beta_i, \gamma_i)$ are reversed.

2.2.2 Volume Source

For a volume source the new ray is created at a random point within the source segment and the direction of the ray is chosen to give isotropic emission.

The random starting point is determined by creating a random point (x_i, y_i, z_i) within a rectangular parallelopiped that encloses the source segment. Then a check is made to determine if the point lies within the segment. If not, new random points are chosen until one is found that does lie within the segment.

To find the directional cosines, random components of a vector are found.

$$\Delta x = \text{a random number } (-1 \leq \Delta x \leq 1)$$

$$\Delta y = \text{a random number } (-1 \leq \Delta y \leq 1)$$

$$\Delta z = \text{a random number } (-1 \leq \Delta z \leq 1)$$

then

$$R = \sqrt{\Delta x^2 + \Delta y^2 + \Delta z^2}$$

If $R \leq 1$, the random components are used. If not, other sets or random components are determined until an appropriate set is found.

Finally

$$\alpha_i = \Delta x/R$$

$$\beta_i = \Delta y/R$$

$$\gamma_i = \Delta z/R$$

2.2.3 Ray Input

The third way to create new rays is to input the starting points and directional cosines of a systematically selected set of rays. Then when a new ray is needed, it is available in a table. This feature is primarily useful in debugging.

2.3 REFLECTION

2.3.1 Specular Reflection

When a ray intersects a specular surface, part or all of the ray is reflected at the same angle with the normal and in the same plane that contains the normal and the impending ray. The directional cosines of the reflected ray are calculated as follows:

$$b = -2\left(\alpha_i\alpha_n + \beta_i\beta_n + \gamma_i\gamma_n\right)$$

$$\alpha_r = \alpha_i + b\alpha_n$$

$$\beta_r = \beta_i + b\beta_n$$

$$\gamma_r = \gamma_i + b\gamma_n$$

where

$$\left.\begin{matrix}\alpha_i\\ \beta_i\\ \gamma_i\end{matrix}\right\} = \text{the directional cosines of the ray}$$

$$\left.\begin{matrix}\alpha_n\\ \beta_n\\ \gamma_n\end{matrix}\right\} = \text{the directional cosines of the normal to the surface.}$$

2.3.2 Diffuse Reflection

Diffuse (Lambertian) reflection is calculated by giving the reflected ray a pseudo-random direction with a Lambertian distribution. Two angles (θ and ϕ) represent the angle between the reflected ray and the normal to the surface, and the angle the projection of the ray onto a plane perpendicular to the normal makes with some line in that plane, respectively.

By definition, a Lambertian distribution is such that the probability distribution $P(\theta)$ varies as $\cos\theta$, while $P(\phi)$ is constant. The problem then is to randomly choose θ and ϕ in a manner that gives the desired probability distributions. One method of doing this is to choose a random $\phi (0 \leq \phi \leq 2\pi)$ and a random $\cos^2\theta$ $(0.0 \leq \cos^2\theta \leq 1.0)$. That is not what has been done in the ZAP code however.

If the reflected ray is a unit vector, the probability distribution of the projection of that ray onto the plane perpendicular to the normal should be constant. This fact is the key to the technique used here.

With uniform random numbers R_i $(0 \leq R_i \leq 1)$ we get the diffusely reflected directional cosines of the ray relative to the normal $(\vec{N})$ and two orthogonal axes $(\vec{P},\vec{Q})$ in the perpendicular plane as follows:

Let

α_R = projection of ray onto $\vec{P}$

β_R = projection of ray onto $\vec{Q}$

γ_R = projection of ray onto $\vec{N}$

Then choose

$$\alpha_R = 2R_i - 1$$

$$\beta_R = 2R_{i+1} - 1$$

If $\alpha_R^2 + \beta_R^2 > 1.0$, choose two new random numbers and calculate new values for α_R and β_R.

Then

$$\gamma = \sqrt{1.0 - \left(\alpha_R^2 + \beta_R^2\right)}$$

Normal $\vec{N}$ has directional cosines $\alpha_n, \beta_n, \gamma_n$.

If $\alpha_n = 1.0$ choose

$$\alpha_P = 0$$

$$\beta_P = 1$$

$$\gamma_P = 0$$

Otherwise the directional cosines of $\vec{P}$ are

$$\alpha_P = \frac{1-\alpha_n^2}{\sqrt{1-\alpha_n^2}}$$

$$\beta_P = \frac{\alpha_n \beta_n}{\sqrt{1-\alpha_n^2}}$$

$$\gamma_P = \frac{\alpha_n \gamma_n}{\sqrt{1-\alpha_n^2}}$$

The directional cosines of $\vec{Q}$ are

$$\alpha_Q = \beta_n\gamma_P - \beta_P\gamma_n$$

$$\beta_Q = \alpha_P\gamma_n - \alpha_n\gamma_P$$

$$\gamma_Q = \alpha_n\beta_P - \alpha_P\beta_n$$

Finally, the directional cosines of the ray are:

$$\alpha_r = \alpha_R\alpha_P + \beta_R\alpha_Q + \gamma_R\alpha_n$$

$$\beta_r = \alpha_R\beta_P + \beta_R\beta_Q + \gamma_R\beta_n$$

$$\gamma_r = \alpha_R\gamma_P + \beta_R\gamma_Q + \gamma_R\gamma_n$$

2.3.3 Percent of Reflection for Dielectrics.

When a ray intersects the surface of a laser rod, lamp, or any other glass component, the percent of the ray to be reflected must be calculated. The ZAP code uses Fresnel's equation for reflection to calculate this percentage.

Let

cos a = cosine of the angle of incidence

cos b = cosine of the angle of refraction

REF_{m1} = refractive index of the material the ray is leaving.

REF_{m2} = refractive index of the material the ray is entering.

then

$$m = \frac{REF_{m1}}{REF_{m2}}$$

$$\cos a = \left|\alpha_i\alpha_n + \beta_i\beta_n + \gamma_i\gamma_n\right|$$

$$\cos b = \left|\alpha_{rf}\alpha_n + \beta_{rf}\beta_n + \gamma_{rf}\gamma_n\right|$$

$$r_s = \left(\frac{\cos b - m \cos a}{\cos b + m \cos a}\right)^2$$

$$r_p = r_s\left(\frac{\cos a \cos b - m\left(1 - \cos^2 a\right)}{\cos a \cos b + m\left(1 - \cos^2 a\right)}\right)$$

$$\text{Percent reflected} = \frac{r_s + r_p}{2}$$

2.4 REFRACTION

When part or all of a ray is transmitted through a surface separating different materials, the transmitted ray is refracted because of the difference in material densities. The directional cosines of the refracted ray are calculated from the following equations.

Let

$$\left.\begin{matrix}\alpha_{rf} \\ \beta_{rf} \\ \gamma_{rf}\end{matrix}\right\} = \text{the directional cosines of the refracted ray}$$

REF_{m1} = the refractive index of the material the ray is leaving

REF_{m2} = the refractive index of the material the ray is entering

$\left.\begin{matrix}\alpha_n \\ \beta_n \\ \gamma_n\end{matrix}\right\}$ = the directional cosines of the normal to the surface at the point of intersection .

$\left.\begin{matrix}\alpha_i \\ \beta_i \\ \gamma_i\end{matrix}\right\}$ = the directional cosines of the impending ray

then

$$a = \frac{REF_{m1}}{REF_{m2}}$$

$$c = \alpha_i\alpha_n + \beta_i\beta_n + \gamma_i\gamma_n$$

$$b = ac\left(-1 + \sqrt{1 + (1-a^2)/a^2c^2}\right)$$

$$\alpha_{rf} = a\alpha_i + b\alpha_n$$

$$\beta_{rf} = a\beta_i + b\beta_n$$

$$\gamma_{rf} = a\gamma_i + b\gamma_n$$

2.5 DEBUGGING

2.5.1 Printer Plots

A printer plot of the geometry cut by a plane may be obtained for as many different planes as desired. In each case a rectangular section of the plane is defined as input. The geometry within this rectangle is the geometry that will be plotted.

The technique used to generate the points that represent the geometric boundaries is as follows: fake rays are created and traced across the plane. Each time an intersection with a boundary occurs, the coordinates of the intersection are noted, and a blank is plotted. The material number is plotted between intersections. Rays are not reflected, and are traced until they leave the area of interest.

The only major restriction in defining the rectangular plotting area is that the rectangle must be completely enclosed by the overall mother region (region number 1). This is no real restriction since the overall mother can be made very large with no loss of computer time or accuracy.

The input required to define the rectangular plotting area consists of three points p_0, p_1, and p_2'. Point p_0 will become the lower left hand corner of the plot and point p_1 will be the lower right hand corner. Point p_2' will be on the top line of the plot.

Fake rays are created at even intervals along the lines that form the top and lefthand sides of the plotting area, and are traced perpendicular to the line on which they are created. The number of rays to be created is determined in such a way that one ray corresponds to each print line and one ray corresponds to each print column.

NX = number of vertical rays

NY = number of horizontal rays

Once an intersection point (x,y,z) has been found, the coordinate system must be rotated and translated to correspond to the plotting area. The equations needed are:

$$\ell_x = \sqrt{(x_1-x_0)^2 + (y_1-y_0)^2 + (z_1-z_0)^2}$$

ℓ_x = length of line p_0p_1

$$\left.\begin{aligned} a_{xx} &= \frac{x_1-x_0}{\ell_x} \\ a_{xy} &= \frac{y_1-y_0}{\ell_x} \\ a_{xz} &= \frac{z_1-z_0}{\ell_x} \end{aligned}\right\} \text{directional cosines of } p_0p_1$$

Point p_2 must be found

$$k = a_{xx}(x_2'-x_0) + a_{xy}(y_2'-y_0) + a_{xz}(z_2'-z_0)$$

$$x_2 = x_2' - k\,a_{xx}$$

$$y_2 = y_2' - k\,a_{xy}$$

$$z_2 = z_2' - k\,a_{xz}$$

then

$$\ell_y = \sqrt{(x_2-x_0)^2 + (y_2-y_0)^2 + (z_2-z_0)^2}$$

ℓ_y = length of line p_0p_2

$$\left.\begin{aligned} a_{yx} &= \frac{x_2-x_0}{\ell_y} \\ a_{yy} &= \frac{y_2-y_0}{\ell_y} \\ a_{yz} &= \frac{z_2-z_0}{\ell_y} \end{aligned}\right\} \quad \text{directional cosines of } p_0p_2$$

Rays are created at equal intervals along the top and lefthand side of the plotting area.

$NX = 130$ = number of print positions to be used

$\Delta s_x = \ell_x/(N-1)$ = interval along horizontal direction.

$\Delta s_y = \frac{10}{6}\Delta s_x$ = interval along the vertical direction

$$Ny = \ell_y/\Delta s_y + 1.5$$

Horizontal ray number n has the starting coordinates:

$$x_s = x_2 - (n - .5)\ \Delta s_y a_{yx}$$

$$y_s = y_2 - (n - .5)\Delta s_y a_{yy}$$

$$z_s = z_2 - (n - .5)\Delta s_y a_{yz}$$

and directional cosines

$$\alpha = a_{xx}$$

$$\beta = a_{xy}$$

$$\gamma = a_{xz}$$

Vertical ray number n has the starting coordinates:

$$x_s = x_2 + (n-1)\Delta s_x a_{xx}$$

$$y_s = y_2 + (n-1)\Delta s_x a_{xy}$$

$$z_s = z_2 + (n-1)\Delta s_x a_{xz}$$

and directional cosines

$$\alpha = -a_{yx}$$

$$\beta = -a_{yy}$$

$$\gamma = -a_{yz}$$

For each intersection point x,y,z the plotting coordinates are calculated as

$$\bar{X} = a_{xx}(x-x_0) + a_{xy}(y-y_0) + a_{xz}(z-z_0)$$

$$\bar{Y} = a_{yx}(x-x_0) + a_{yy}(y-y_0) + a_{yz}(z-z_0)$$

2.5.2 Random Errors

The random errors in the results of the ZAP program are due to statistical variations in the number of rays passing through a particular segment and due to the variation in the amount of energy deposited by each ray passing through this segment. The latter variation is due to variations in the path length through the segment and variations in the ray energy upon entry into the segment. It turns out that the variation in the number of rays usually contributes to the largest fraction of the random error.

The random error is displayed in the output as a percentage error of one standard deviation. When the number of rays contributing to a segment is less than four, ***** is printed to indicate the lack of data. Large errors are by their very nature unreliable as their calculation is based on unreliable results. An error larger than 20% indicates unreliable results, where an error below 5% indicates usable results.

The percentage error is calculated according to the equation presented below:

$$ER_i = \sqrt{\frac{\sum E^2 - \frac{1}{N}\left(\sum E\right)^2}{\sum E}}$$

where

ER_i	Percentage error in segment i for one standard deviation
N	Total number of rays in the problem
E	Energy deposited in segment i by a ray
$\sum E$	Total energy deposited in segment i

2.6 GEOMETRY

2.6.1 Equations for a Plane

A plane is defined by the directional cosines of the normal to the plane and the coordinates of a point that lies on the plane. An additional piece of information needed in many of the equations is the distance from the origin to the plane. The directional cosines of the normal must be such that the normal vector points from the origin to the plane. The calculation of the distance from the origin to the plane provides a check on the direction, since the distance will be negative if the vector points in the wrong direction.

Define:

$$\left.\begin{matrix}\alpha_k\\ \beta_k\\ \gamma_k\end{matrix}\right\} = \text{the directional cosines of the normal to the plane}$$

$$\left.\begin{matrix}x_k\\ y_k\\ z_k\end{matrix}\right\} = \text{the coordinates of a point on the plane}$$

2.6.1.1 Distance from the Origin to the Plane

$$d_k = \alpha_k x_k + \beta_k y_k + \gamma_k z_k$$

2.6.1.2 Intersection of a ray with a plane:

Let

L = distance along the ray to the point of intersection

$$\left.\begin{matrix}\alpha_i\\ \beta_i\\ \gamma_i\end{matrix}\right\} = \text{directional cosines of the ray}$$

$$\left.\begin{matrix} x_i \\ y_i \\ z_i \end{matrix}\right\} = \text{coordinates of the starting point of the ray}$$

then

$$L = \frac{d_k - (\alpha_k x_i + \beta_k y_i + \gamma_k z_i)}{\alpha_i \alpha_k + \beta_i \beta_k + \gamma_i \gamma_k}$$

The point of intersection (x,y,z) can then be calculated:

$$x = x_i + L\alpha_i$$

$$y = y_i + L\beta_i$$

$$z = z_i + L\gamma_i$$

2.6.1.3 Normal to the Point of Intersection

In the case of a plane, the normal to the point of intersection does not require an actual calculation, since the normal to the plane is the same everywhere and is part of the definition of the plane. Hence:

$$\alpha_n = \alpha_k$$

$$\beta_n = \beta_k$$

$$\gamma_n = \gamma_k$$

2.6.1.4 Position of Point Relative to Plane

In determining if a point is inside a given segment, it is necessary to determine on which side of a plane the point lies. This requires finding the perpendicular distance from the plane to the point.

$$D = \alpha_k x_i + \beta_k y_i + \gamma_k z_i - d_k$$

where

$$\left.\begin{matrix} x_i \\ y_i \\ z_i \end{matrix}\right\} = \text{the coordinates of the point}$$

2.6.2 Equations for a Cylindrical Surface

A cylindrical surface is defined by the directional cosines of the cylinder axis, the coordinates of a point on the axis, and the radius of the cylinder.

Define

$$\left.\begin{matrix} \alpha_k \\ \beta_k \\ \gamma_k \end{matrix}\right\} = \text{directional cosines of cylinder axis.}$$

$$\left.\begin{matrix} x_k \\ y_k \\ z_k \end{matrix}\right\} = \text{coordinates of a point on the axis.}$$

d_k = the radius of the cylinder.

2.6.2.1 Intersection of a Ray with a Cylinder

Let

L	=	distance along the ray to the poin of intersection.
α_i, β_i, γ_i	=	directional cosines of the ray.
x_i, y_i, z_i	=	coordinates of the starting point of the ray

Then

$$\Delta x = x_i - x_k$$

$$\Delta y = y_i - y_k$$

$$\Delta z = z_i - z_k$$

$$xx = \alpha_i\alpha_k + \beta_i\beta_k + \gamma_i\gamma_k$$

$$yy = \alpha_i\Delta x + \beta_i\Delta y + \gamma_i\Delta z$$

$$zz = \alpha_k\Delta x + \beta_k\Delta y + \gamma_k\Delta z$$

$$(AA)^2 = \Delta x^2 + \Delta z^2 + \Delta z^2$$

$$L = \frac{(zz)\,(xx) - yy \pm \sqrt{(yy-zz*xx)^2 - (1-xx)^2(AA^2-zz^2-d_k 2)}}{\left(1-xx^2\right)}$$

2.6.2.2 In or Out of a Cylinder

To determine if a point lies inside a cylinder, it is necessary to calculate the distance from the point to the cylinder axis and compare this distance with the cylinder radius.

Let

D = distance of point from cylinder axis

$$\left.\begin{matrix} x_i \\ y_i \\ z_i \end{matrix}\right\} = \text{coordinates of a point}$$

Then

$$\Delta x = x_i - x_k$$

$$\Delta y = y_i - y_k$$

$$\Delta z = z_i - z_k$$

$$D^2 = \Delta x^2 + \Delta y^2 + \Delta z^2 - \left(\alpha_k \Delta x + \beta_k \Delta y + \gamma_k \Delta z\right)^2$$

if $D^2 < d_k^2$ point lies inside cylinder.

2.6.2.3 Normal to a Cylinder

Let

$$\left.\begin{matrix} x \\ y \\ z \end{matrix}\right\} = \text{a point on the cylinder surface}$$

$$\left.\begin{matrix} \alpha_n \\ \beta_n \\ \gamma_n \end{matrix}\right\} = \begin{matrix}\text{the directional cosines of the normal} \\ \text{to the cylinder at the point } (x,y,z)\end{matrix}$$

Calculate

$$\Delta x = x - x_k$$

$$\Delta y = y - y_k$$

$$\Delta z = z - z_k$$

$$C = \alpha_k \Delta x + \beta_k \Delta y + \gamma_k \Delta z$$

$$\alpha_n = \frac{\Delta x - C\alpha_k}{d_k}$$

$$\beta_n = \frac{\Delta y - C\beta_k}{d_k}$$

$$\gamma_n = \frac{\Delta z - C\gamma_k}{d_k}$$

2.6.3 Equations for a Sphere

A sphere is defined by the coordinates of the center and the radius.

Define:

$$\left.\begin{matrix} x_k \\ y_k \\ z_k \end{matrix}\right\} = \text{the coordinates of the center of the sphere}$$

d_k = the radius of the sphere

2.6.3.1 Intersection of a Ray with a Sphere

Let

L = distance along the ray to the point of intersection

$$\left.\begin{matrix} \alpha_i \\ \beta_i \\ \gamma_i \end{matrix}\right\} = \text{directional cosines of the ray}$$

$$\left.\begin{matrix} x_i \\ y_i \\ z_i \end{matrix}\right\} = \text{coordinates of the starting point of the ray}$$

then

$$\Delta x = x_i - x_k$$

$$\Delta y = y_i - y_k$$

$$\Delta z = z_i - z_k$$

$$B = \Delta x \alpha_i + \Delta y \beta_i + \Delta z \gamma_i$$

$$C = \Delta x^2 + \Delta y^2 + \Delta z^2 - d_k^2$$

$$L = -B \pm \sqrt{B^2 - C}$$

2.6.3.2 In or Out of a Sphere

To determine if a point is inside a sphere, one must calculate the distance from the point to the center of the sphere and compare this with the radius.

Let

D = distance of point from center of sphere

$$\left.\begin{matrix} x_i \\ y_i \\ z_i \end{matrix}\right\} = \text{coordinates of the point}$$

then

$$D^2 = (x_i - x_k)^2 + (y_i - y_k)^2 + (z_i - z_k)^2$$

If $D^2 < d_k^2$, the point is inside the sphere.

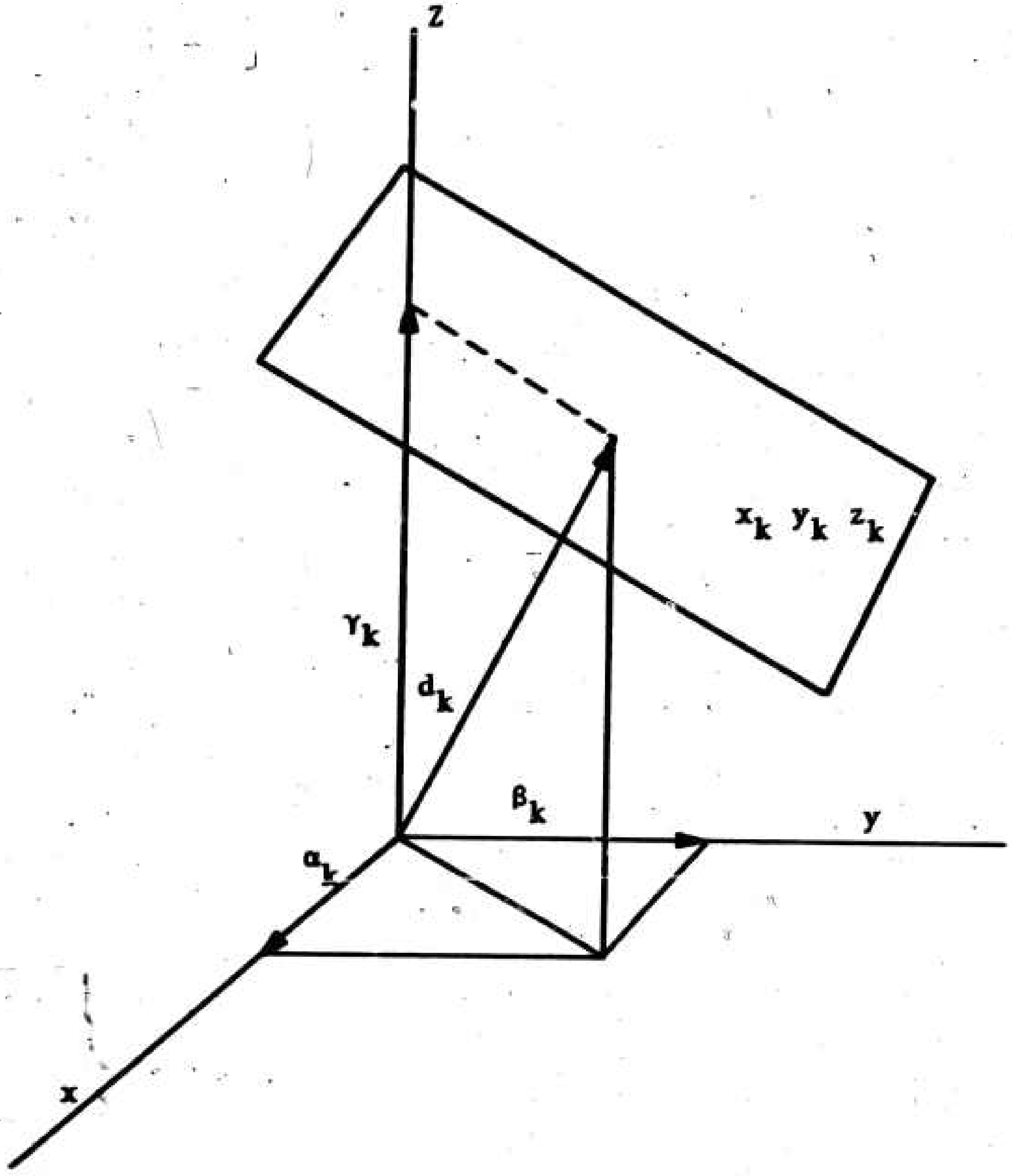


Figure 2.1 A plane whose normal is not parallel to any of the major axis.

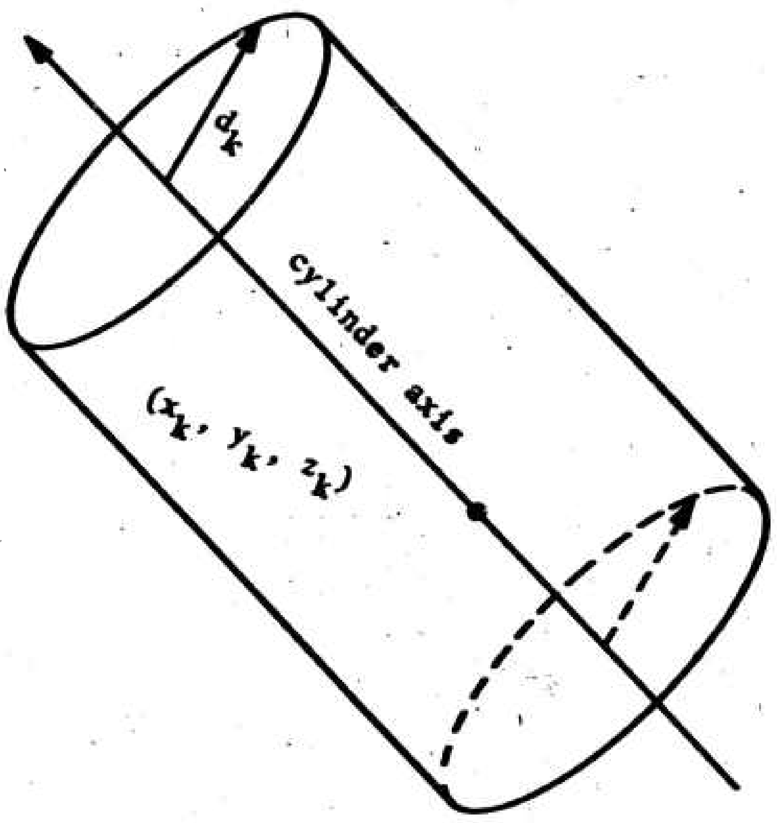


Figure 2.2 Cylinder whose axis is not parallel to any of the major axis.

2.6.3.3 Normal to a Sphere

Let

$$\left.\begin{array}{c} x \\ y \\ z \end{array}\right\} = \text{a point on the surface of the sphere}$$

$$\left.\begin{array}{c} \alpha_n \\ \beta_n \\ \gamma_n \end{array}\right\} = \begin{array}{l}\text{the directional cosines of the normal} \\ \text{to the surface at the point } (x,y,z)\end{array}$$

Calculate

$$\alpha_n = (x-x_k)/d_k$$

$$\beta_n = (y-y_k)/d_k$$

$$\gamma_n = (z-z_k)/d_k$$

2.6.4 Equations for a Conic Cylinder

The conic cylinder is limited to one whose conic axis is perpendicular to the Z axis and whose cylindrical axis is parallel to the Z axis. In this case, only the x-y plane must be considered in defining the surface. The conic is defined by the coordinates of the focus, the directional cosines of the conic axis, and the coordinates of two points which lie on the surface. In addition, the eccentricity and the distance from the focus to the directrix are calculated for use in the equations. See Figure 2.4.

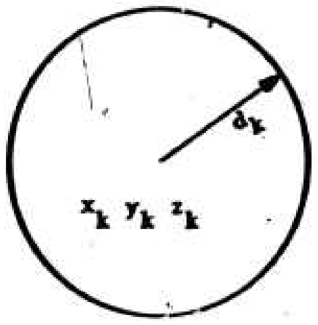


Figure 2.3 Sphere

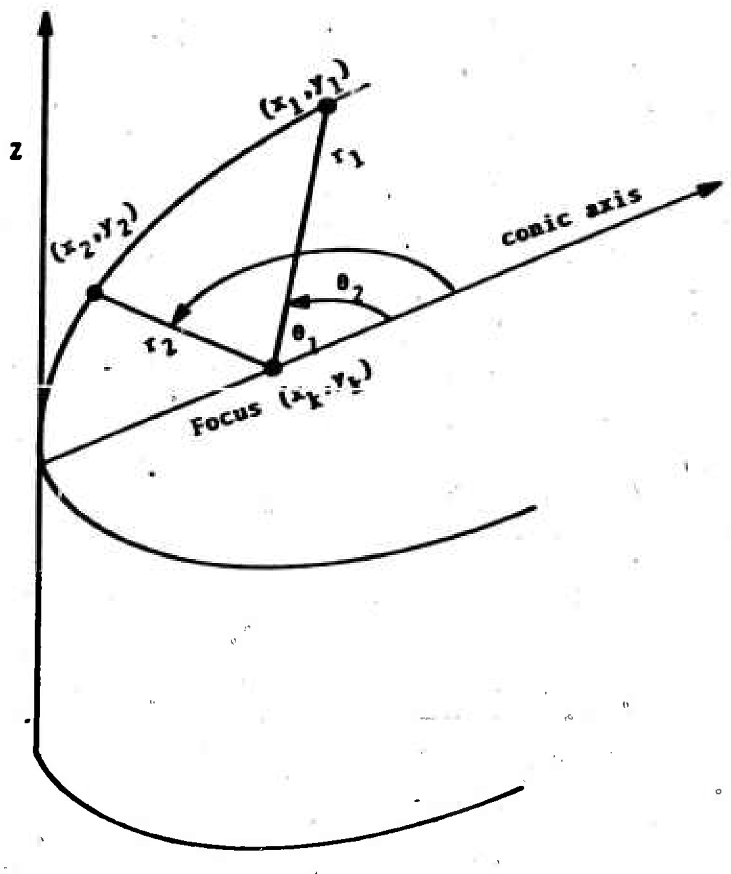


Figure 2.4 Conic cylinder with axis parallel to Z-axis

Define

$$\left.\begin{matrix}\alpha_k \\ \beta_k\end{matrix}\right\} = \text{directional cosines of the conic axis}$$

$$\left.\begin{matrix}x_k \\ y_k\end{matrix}\right\} = \text{coordinates of the focus}$$

$$\left.\begin{matrix}x_1 \\ y_1 \\ x_2 \\ y_2\end{matrix}\right\} = \text{coordinates of two points on the surface}$$

e_k = eccentricity

d_k = distance from focus to directrix

2.6.4.1 Eccentricity and Distance from Focus to Directrix

$$r_1 = \sqrt{(x_1-x_k)^2 + (y_1-y_k)^2}$$

$$r_2 = \sqrt{(x_2-x_k)^2 + (y_2-y_k)^2}$$

$$\alpha_1 = \frac{x_1-x_k}{r_1}$$

$$\beta_1 = \frac{y_1-y_k}{r_1}$$

$$\alpha_2 = \frac{x_2 - x_k}{r_2}$$

$$\beta_2 = \frac{y_2 - y_k}{r_2}$$

$$\cos\theta_1 = \alpha_k\alpha_1 + \beta_k\beta_1$$

$$\cos\theta_2 = \alpha_k\alpha_2 + \beta_k\beta_2$$

$$e_k = \frac{r_1 - r_2}{r_1 \cos\theta_1 + r_2 \cos\theta_2}$$

$$d_k = \frac{r_1 r_2 (\cos\theta_1 - \cos\theta_2)}{r_1 - r_2}$$

2.6.4.2 Intersection of a Ray with a Conic Cylinder

Let

$$\left.\begin{array}{l} x_i \\ y_i \\ z_i \end{array}\right\} = \text{coordinates of starting point of ray}$$

$$\left.\begin{array}{l} \alpha_i \\ \beta_i \\ \gamma_i \end{array}\right\} = \text{directional cosines of the ray}$$

L = distance along the ray to the point of intersection.

then

$$\Delta x = x_i - x_k$$

$$\Delta y = y_i - y_k$$

$$\cos\theta = \sqrt{1 - \gamma_i^2}$$

$$\alpha' = \alpha_i/\cos\theta$$

$$\beta' = \beta_i/\cos\theta$$

$$EE = \alpha' \Delta x + \beta' \Delta y$$

$$FF = \alpha_k \Delta x + \beta_k \Delta y$$

$$GG = \alpha_k \alpha' + \beta_k \beta'$$

$$BB^2 = \Delta x^2 + \Delta y^2$$

$$P = 1 - e_k^2 \, GG^2$$

$$H = EE - e_k^2 \, GG\left(FF + d_k^2\right)$$

$$Q = BB^2 - e_k^2\left(FF + d_k^2\right)$$

$$L = \frac{-H \pm \sqrt{H^2 - PQ}}{P \cos\theta}$$

2.6.4.3 In or Out of a Conic Cylinder

To determine if a point (x_i, y_i) lies inside of a conic cylinder it is necessary to calculate the distance from the focus to the surface in the direction of the point, and the distance from the focus to the point and then compare the two distances.

Let

$$\left.\begin{array}{l} x_i \\ y_i \end{array}\right\} = \text{the coordinates of the point}$$

D = the distance from focus to point

R = distance from focus to surface

then

$$\Delta x = x_i - x_k$$

$$\Delta y = y_i - y_k$$

$$D = \sqrt{\Delta x^2 + \Delta y^2}$$

$$\alpha' = \Delta x / D$$

$$\beta' = \Delta y / D$$

$$R = \frac{d_k\ e_k}{1 - e_k\left(\alpha_k \alpha' + \beta_k \beta'\right)}$$

if $D < R$, the point is inside the conic.

2.6.4.4 Normal to a Conic Cylinder

Let

$$\left.\begin{array}{l}\alpha_n\\ \beta_n\\ \gamma_n\end{array}\right\} = \text{directional cosines of the normal to the surface at the point } (x,y,z)$$

then

$$\Delta x = x - x_k$$

$$\Delta y = y - y_k$$

$$DD = \sqrt{\Delta x^2 + \Delta y^2}$$

$$\alpha' = \Delta x / DD$$

$$\beta' = \Delta y / DD$$

$$\cos\theta = \alpha_k \alpha' + \beta_k \beta'$$

$$\sin\theta = \alpha_k \beta' - \alpha' \beta_k$$

$$\alpha_n = \frac{\alpha_k \cos\theta - \beta_k \sin\theta - e_k \alpha_k}{\sqrt{1 + e_k^2 - 2e_k \cos\theta}}$$

$$\beta_n = \frac{\alpha_k \sin\theta + \beta_k \cos\theta - e_k \beta_k}{\sqrt{1 + e_k^2 - 2e_k \cos\theta}}$$

$$\gamma_n = 0$$

2.6.5 Equations for a Cone

A right circular half cone whose axis is parallel to the Z axis is defined by the coordinates of the vertex and the coordinates of a point on the surface of the cone. If the point lies above the vertex, the half cone is a cup. If it lies below the vertex the half cone is a cap (see Figure 2.5).

Define:

$$\left.\begin{array}{l} x_k \\ y_k \\ z_k \end{array}\right\} = \text{the coordinates of the vertex}$$

$$\left.\begin{array}{l} x_1 \\ y_1 \\ z_1 \end{array}\right\} = \text{the coordinates of a point on the surface}$$

$$d_k = \frac{(z_1-z_k)^2}{(x_1-x_k)^2 + (y_1-y_k)^2 + (z_1-z_k)^2}$$

$$e_k = z_1-z_k$$

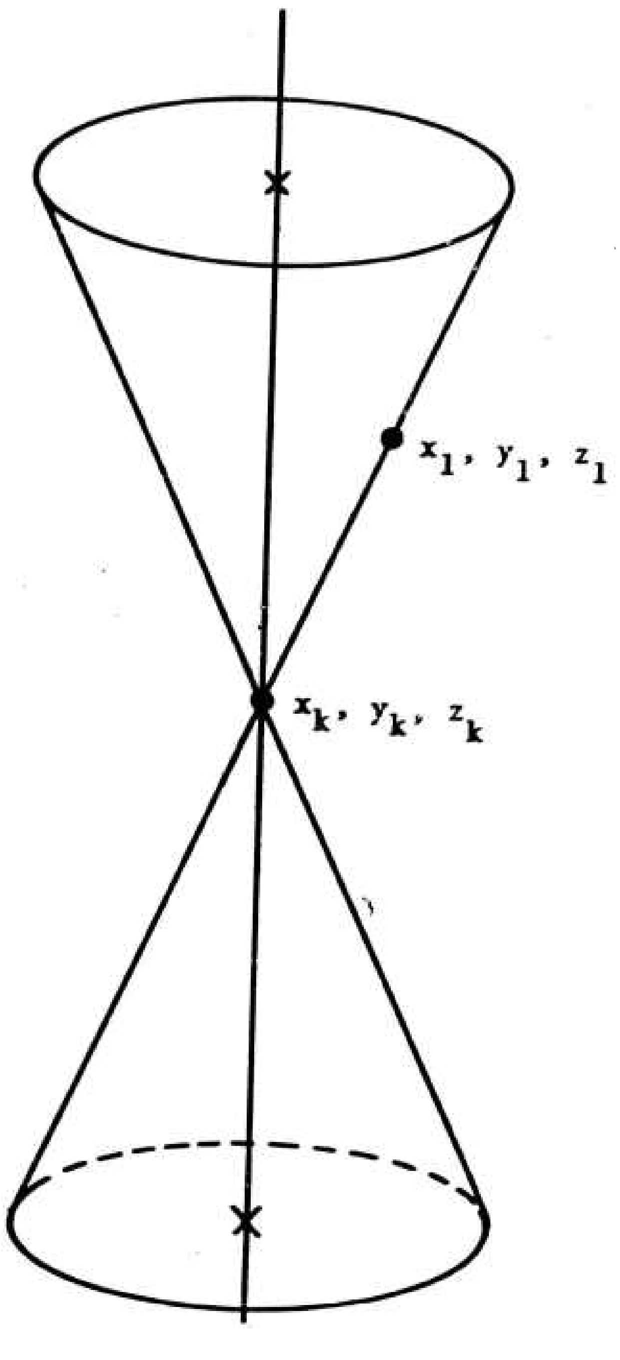


Figure 2.5 Cone with axis parallel to Z-axis

2.6.5.1 Intersection of a Ray with a Half Cone

Let

$$\left.\begin{matrix} x_i \\ y_i \\ z_i \end{matrix}\right\} = \text{coordinates of the starting point of a ray}$$

$$\left.\begin{matrix} \alpha_i \\ \beta_i \\ \gamma_i \end{matrix}\right\} = \text{directional cosines of a ray}$$

L = distance along the ray to the point of intersection.

Then

$$\Delta x = x_i - x_k$$

$$\Delta y = y_i - y_k$$

$$\Delta z = z_i - z_k$$

$$A = \gamma_i^2 - d_k$$

$$B = \left(1-d_k\right)\gamma_k \Delta z - d_k\left(\alpha_i \Delta x + \beta_i \Delta y\right)$$

$$C = \left(1-d_k\right)\Delta z^2 - d_k\left(\Delta x^2 + \Delta y^2\right)$$

$$L_{\pm} = \frac{-B \pm \sqrt{B^2 - AC}}{A}$$

We must now choose the smallest positive length that gives an intersection point in the proper half of the cone. Let

$$e_+ = \left(z_i + \gamma_i L_+\right)\left(e_k\right)$$

$$e_- = \left(z_i + \gamma_i L_-\right)\left(e_k\right)$$

if e_+ is positive, L_+ gives an intersection in the proper half of the cone.

if e_- is positive, L_- gives an intersection in the proper half of the cone.

2.6.5.2 In or Out of a Half Cone

To determine if a point (x_i, y_i, z_i) lies inside of a half cone, the following procedure is used.

$$\Delta x = x_i - x_k$$

$$\Delta y = y_i - y_k$$

$$\Delta z = z_i - z_k$$

$$EP = \Delta z * e_k$$

$$FP = \Delta z^2 - d_k\left(\Delta x^2 + \Delta y^2 + \Delta z^2\right)$$

if $(FP)(EP) > 0$, the point lies inside the half cone.

2.6.5.3 Normal to a Cone

Let

$$\left.\begin{array}{l}\alpha_n\\ \beta_n\\ \gamma_n\end{array}\right\} = \text{the directional cosines of the normal to the surface at the point } (x,y,z)$$

then

$$\Delta x = x - x_k$$

$$\Delta y = y - y_k$$

$$\Delta_z = z - z_k$$

$$R = \sqrt{d_k^2\left(\Delta x^2 + \Delta y^2\right) + \left(1-d_k\right)^2 \Delta z^2}$$

$$\alpha_n = d_k \Delta x/R$$

$$\beta_n = d_k \Delta y/R$$

$$\gamma_n = -\left(1-d_k\right) \Delta z/R$$

2.6.6 Equations for an Ellipsoid of Revolution

The ellipsoid of revolution must have its axis of revolution parallel to the Z axis. It is defined by the coordinates of one of the vertices (x_k, y_k, z_k), the coordinates of a point on the surface (x_1, y_1, z_1) and the Z coordinate of the focus (z_f) nearest to the vertex chosen. See Figure 2.6.

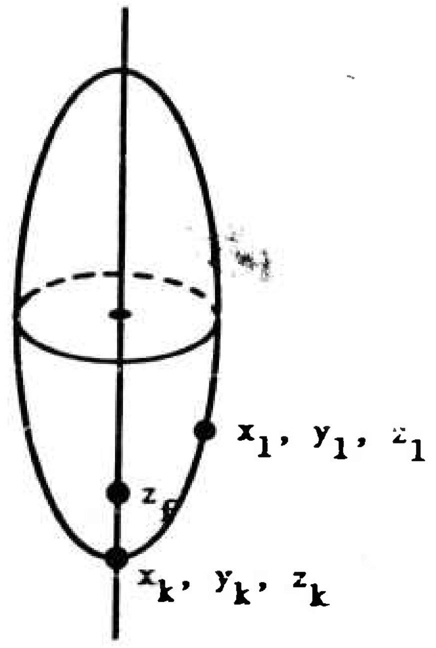


Figure 2.6 Ellipsoid of Revolution with axis parallel to Z-axis

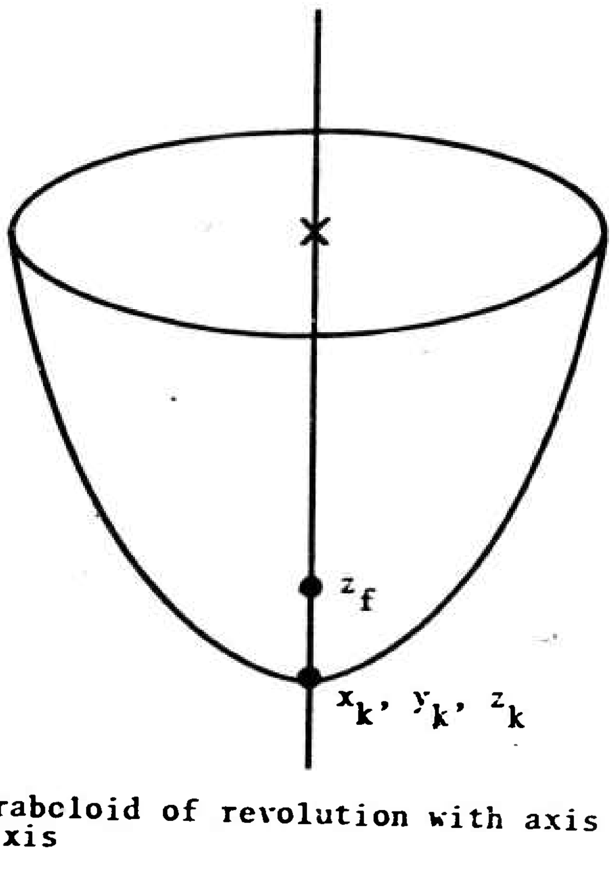


Figure 2.7 Parabcloid of revolution with axis parallel to Z-axis

Let

$$f = z_f - z_k$$

A restriction on the choice of the point (x_1, y_1, z_1) is:

$$2(z_1 - z_k)\, f - (z_1 - z_k)^2 \le (x_1 - x_k)^2 + (y_1 - y_k)^2 \le 4f(z_1 - z_k)$$

The parameters a^2 and b are calculated as follows:

$$W^2 = (x_1 - x_k)^2 + (y_1 - y_k)^2$$

$$z^* = z_1 - z_k$$

$$SQ = \text{sign}(f) * \sqrt{(z^* - f)^2 + W^2}$$

$$b = (z^* + f + SQ) \Big/ \left(4 - \frac{W^2}{z^* f}\right)$$

$$a^2 = b^2 - (b - f)^2$$

2.6.6.1 Intersection of a Ray with the Surface

$$\Delta x = x_i - x_k$$

$$\Delta y = y_i - y_k$$

$$\Delta z = z_i - z_k$$

$$C = 1 - \frac{\Delta x^2 + \Delta y^2}{a^2} - \frac{(\Delta z - b)^2}{b^2}$$

$$B = -\left[\frac{\alpha_i \Delta x + \beta_i \Delta y}{a^2} + \frac{\gamma_i (\Delta z - b)}{b^2}\right]$$

$$A = -\left[\frac{\alpha_i^2+\beta_i^2}{a^2} + \frac{\gamma_i^2}{b^2}\right]$$

if $B^2-AC < 0$, there is no intersection.

Calculate

$$L_\pm = \frac{-B \pm \sqrt{B^2-AC}}{A}$$

The intersection of interest is the minimum positive value of $L_\pm$.

2.6.6.2 In or Out of an Ellipsoid of Revolution

To determine if point (x_i, y_i, z_i) is inside of the surface calculate:

$$F(\vec{P}) = 1 - \frac{(x_i-x_k)^2 + (y_i-y_k)^2}{a^2} - \frac{(z_i-z_k-b)^2}{b^2}$$

if $F(P) > 0$, the point is inside of the ellipsoid.

2.6.6.3 Normal to the Surface at a Point (x,y,z)

$$R = \sqrt{\frac{(x-x_k)^2 + (y-y_k)^2}{a^4} + \frac{(z-z_k-b)^2}{b^4}}$$

The directional cosines of the normal are:

$$\alpha_n = \frac{x-x_k}{a^2 R}$$

$$\beta_n = \frac{y-y_k}{a^2 R}$$

$$\gamma_n = \frac{z - z_k - b}{b^2 R}$$

2.6.7 Equations for a Paraboloid of Revolution

A paraboloid of revolution is limited to the case where the axis of revolution is parallel to the Z axis. It is defined by providing the coordinates of the vertex, and the Z coordinate of the focus. If the focus is above the vertex the figure is a cup. If the focus is below the vertex the figure is a cap. See Figure 2.7.

Define:

$$\left.\begin{array}{l} x_k \\ y_k \\ z_k \end{array}\right\} = \text{the coordinates of the vertex}$$

z_f = the z coordinate of the focus

$f = z_f - z_k$

2.6.7.1 Intersection of a Ray with a Paraboloid of Revolution

Let:

$$\left.\begin{array}{l} \alpha_i \\ \beta_i \\ \gamma_i \end{array}\right\} = \text{directional cosines of the ray}$$

$$\left.\begin{matrix} x_i \\ y_i \\ z_i \end{matrix}\right\} = \text{starting point of the ray}$$

Then

$$C = 4f(z_i - z_k) - (x_i - x_k)^2 - (y_i - y_k)^2$$

$$B = 2f\gamma_i - \alpha_i(x_i - x_k) - \beta_i(y_i - y_k)$$

$$A = -(\alpha_i^2 + \beta_i^2)$$

if $B^2 < Ac$ there is no intersection

$$L_\pm = \frac{-B \pm \sqrt{B^2 - AC}}{A}$$

Choose the minimum positive value of $L_\pm$

2.6.7.2 In or Out of a Paraboloid of Revolution

$$F(\vec{P}) = 4f(z_i - z_k) - (x_i - x_k)^2 - (y_i - y_k)^2$$

if $F(\vec{P}) > 0$, the point (x_i, y_i, z_i) lies inside.

2.6.7.3 Normal to a Point on the Surface

Let

$$\left.\begin{matrix} x \\ y \\ z \end{matrix}\right\} = \text{a point on the surface}$$

$$\left.\begin{matrix} \alpha_n \\ \beta_n \\ \gamma_n \end{matrix}\right\} = \text{the directional cosines of the normal to the surface at the point } (x,y,z)$$

Calculate

$$R = \sqrt{(x-x_k)^2 + (y-y_k)^2 + 4f^2}$$

$$\alpha_n = \frac{x-x_k}{R}$$

$$\beta_n = \frac{y-y_k}{R}$$

$$\gamma_n = \frac{-2f}{R}$$

2.6.8 Equations for a Hyperboloid of Revolution

A hyperboloid of revolution whose axis is parallel to the Z axis is defined by the coordinates of the vertex of the sheet of interest (x_k, y_k, z_k), the Z coordinate of the focus of the sheet of interest (z_f) and the coordinates of a point on the surface of either sheet (x_1, y_1, z_1). See Figure 2.8.

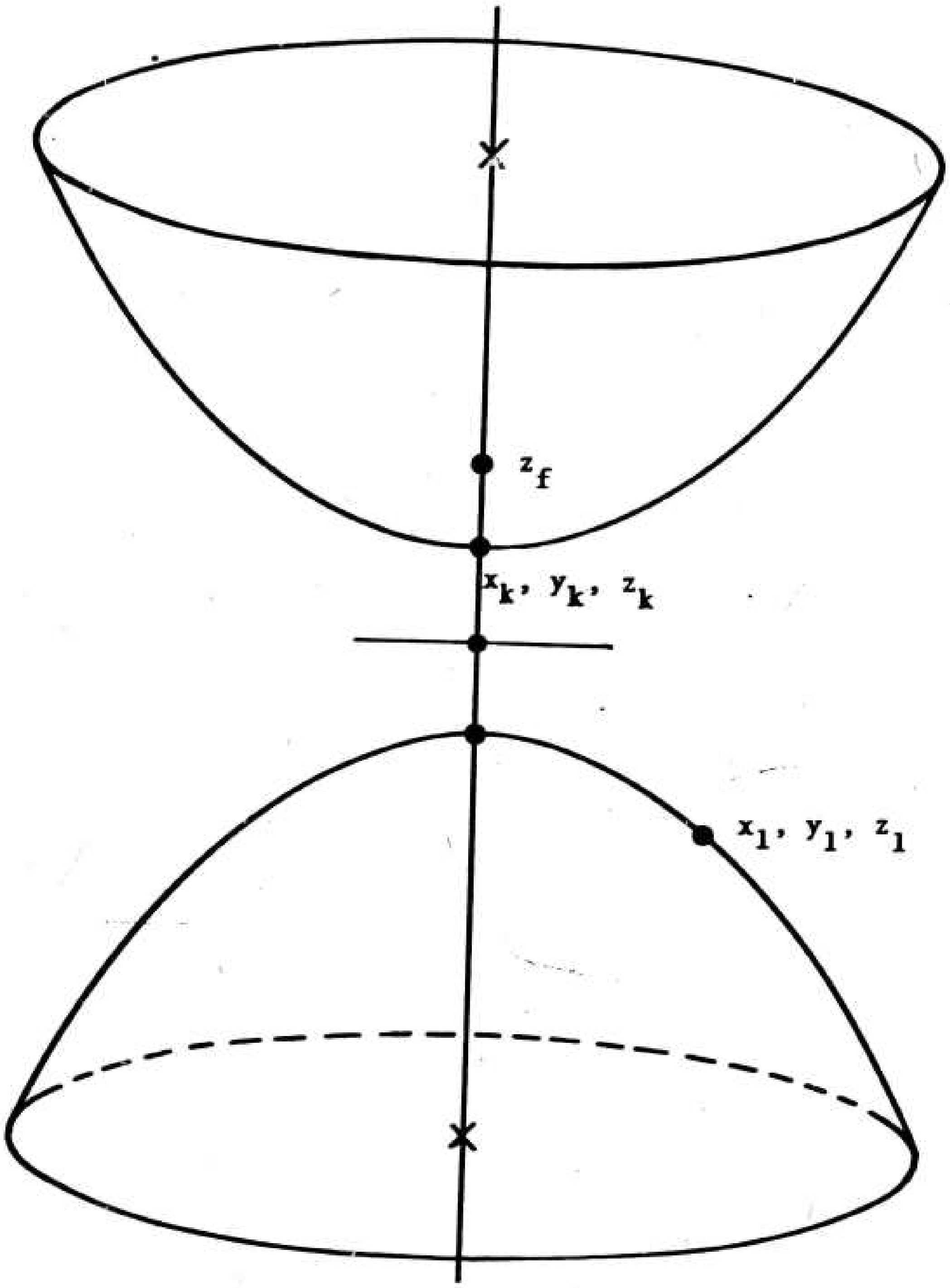


Figure 2.8 Hyperboloid of Revolution

Let

$$f = z_f - z_k$$

A restriction on the choice of the point (x_1, y_1, z_1) is:

$$4f(z_1 - z_k) < (x_1 - x_k)^2 + (y_1 - y_k)^2$$

The parameters a^2 and b are calculated as follows:

$$W^2 = (x_1 - x_k)^2 + (y_1 - y_k)^2$$

$$z^* = z_1 - z_k$$

$$SQ = \text{Sign}\ (z^*) * \sqrt{(z^* - f)^2 + W^2}$$

$$b = (z^* + f + SQ) \Big/ \left(\frac{W^2}{z^* f} - 4\right)$$

$$a^2 = (b+f)^2 - b^2$$

2.6.8.1 Intersection of a Ray with the Surface

$$\Delta x = x_i - x_k$$

$$\Delta y = y_i - y_k$$

$$\Delta z = z_i - z_k$$

$$C = -1 - \frac{\Delta x^2 + \Delta y^2}{a^2} + \frac{(\Delta z + b)^2}{b^2}$$

$$B = \frac{\gamma(\Delta z + b)}{b^2} - \frac{\alpha \Delta x + \beta \Delta y}{a^2}$$

$$A = \frac{\gamma^2}{b^2} - \frac{\alpha^2+\beta^2}{a^2}$$

if $B^2-AC < 0$ there is no intersection.

Calculate

$$L_\pm = \frac{-B \pm \sqrt{B^2-AC}}{A}$$

The intersection of interest is the minimum positive value of $L_\pm$ that will give an intersection on the desired sheet.

2.6.8.2 In or Out of a Hyperboloid of Revolution

To determine if point (x_i,y_i,z_i) is inside of the surface, calculate:

$$F(\vec{P}) = -1 - \frac{\Delta x^2+\Delta y^2}{a^2} + \frac{(\Delta z+b)^2}{b^2}$$

If $F(\vec{P}) > 0$ and $\Delta z*f > 0$, the point is inside.

2.6.8.3 <u>Normal to a Point on the Surface</u>

Let

$$\left.\begin{matrix} x \\ y \\ z \end{matrix}\right\} = \text{a point on the surface}$$

$$\left.\begin{array}{l}\alpha_n\\ \beta_n\\ \gamma_n\end{array}\right\} = \text{the directional cosines of the normal to the surface at the point } (x,y,z)$$

Calculate

$$R = \sqrt{\frac{\Delta x^2 + \Delta y^2}{a^4} + \frac{(\Delta z+b)^2}{b^4}}$$

$$\alpha_n = \frac{\Delta x}{a^2 R}$$

$$\beta_n = \frac{\Delta y}{a^2 R}$$

$$\gamma_n = -\frac{\Delta z+b}{b^2 R}$$

2.6.9 Equations for a Helix

A helix whose main axis is parallel to the Z axis is defined by

$$\left.\begin{array}{l}x_h\\ y_h\end{array}\right\} = \text{coordinates of a point on the axis of the helix}$$

z_h = Point on the helical wire in the positive x direction from the axis of the helix

κ = Parameter defining the distance between successive coils (D) $D = |2\pi\kappa|$ if $\kappa < 0$, coil is left-handed.

ρ = radius from axis to helical wire

a = radius of the helical tube.

The equations used are quite voluminous. They are derived and presented in Appendix A.1.

3. INPUT - OUTPUT

3.1 SETUP CONSIDERATIONS

The use of any large generalized computer program requires a certain amount of knowledge of how the program works and requires a learning process the same as with a piece of complicated machinery. The more general a program is, the more understanding and experience is required to effectively make use of it. The ZAP code is no exception in this respect.

In particular, a thorough understanding of the mother-daughter relationship and its consequences is very important, since this is the basis of the ZAP technique. To try to set up complicated geometries without this understanding will invariably result in boundaries existing in areas where they are not supposed to exist. To cut off the extension of a plane for example, requires that the area where the plane actually exists be enclosed in a Mother segment. Then the plane will not extend outside that Mother segment.

Unfortunately, with Monte Carlo techniques gross errors can occur in the setup of a problem without causing any indication that these errors exist. Boundaries may exist in areas where they are not intended without ever being obvious in the results. Therefore, extreme care and thought should be put into the setup of a problem. To help spot a bad setup, test data points and geometry plots have been included in the program.

The bad effects of boundaries extending into areas where they do not belong has perhaps been over emphasized in the above paragraphs. Regardless of the type of boundary under consideration, it is treated as a dummy boundary and has no ill effects if the same material exists on each side of the boundary. Conversely, it must be kept in mind that if the same material or two different materials with the same index of refraction are separated by a boundary, that boundary will be treated as a dummy regardless of how it is defined.

It is highly recommended that anyone planning extensive use of the ZAP program should become as familiar as is possible with the inner workings of the code.

3.1.1 Miscellaneous Rules

1. Planes must not pass through the origin (0,0,0).
2. Each Mother segment must also exist as a daughter segment (except for the overall Mother segment).
3. The overall Mother segment must be segment #1.
4. Each Mother segment must have at least one daughter.
5. A Mother segment must completely contain each of its daughters. Conversely a daughter must be completely contained by its Mother.
6. Different materials that are to be separated by a real boundary must not have the same refractive index.
7. Planes defined for geometry plots must not coincide with a real plane in the geometric system.
8. A segment must be "totally" confined by its confining boundaries. For example, an open ended cylinder does not qualify as a segment.

9. Any rectangular area to be plotted must lie completely within the overall Mother segment.

3.1.2 User Routines

Provisions have been made to allow the user to provide subroutines to handle certain functions within the program. A description of these routines is given below as they apply to the functions desired.

3.1.2.1 Wavelength Dependent Absorption Coefficients

In a multifrequency problem the user must provide a subroutine or subroutines that calculate and store the absorption coefficients as a function of wavelength and material number. The name of the subroutine for each material is given on the material data card and must be of the form:

ABSX

where X is a number from 1 to 9.

The argument list for the subroutine is:

```
SUBROUTINE ABSX(XLAM,FMAX,TSTG,M)
```

where

XLAM	=	name of the array that contains frequencies.
FMAX	=	the number of frequencies (integer).
TSTG	=	storage area for absorption coefficients from F=1 to F=FMAX.
M	=	material number.

This subroutine must determine and store the absorption coefficients for material M into the array TSTG(F), F-1,FMAX.

One subroutine may be provided for each material or the same subroutine may be used for different materials.

3.1.2.2 Wavelength Dependent Intensities

In a multifrequency run, the ray intensity may vary with wavelength. Therefore a subroutine to provide intensity as a function of wavelength must be provided. The name of the subroutine to be used for each lamp type is given on the lamp data card and will be of the form:

INTENX

where X is an integer from 1 to 9.

The argument list is:

```
SUBROUTINE INTENX(XLAM,FMAX,TSTG,LAMNO)
```

where:

XLAM	=	name of the frequency array
FMAX	=	the number of frequencies (integer)
TSTG	=	an array to store intensity as a function of wavelength for lamp number LAMNO
LAMNO	=	lamp number.

This subroutine must determine and store ray intensities for lamp number LAMNO into the array:

TSTG(F),F=1,FMAX

One subroutine may be provided for each lamp number, or the same routine may be used for different lamp numbers.

3.1.2.3 Surface Source Distribution

When a surface source is used, a subroutine must be provided that will give the angles used to calculate the directional cosines for a given ray. The name of this routine is given on the lamp data card and must be of the form:

ANGLEX

where X is a number from 1 to 9.

The argument list for the subroutine is:

```
SUBROUTINE ANGLEX(TH,PHI)
```

where

TH	=	an angle (θ) with the normal to the surface.
PHI	=	an angle (ϕ) in the plane perpendicular to the normal.

This routine must provide values for θ and ϕ where:

$$0 \leq \theta \leq \pi/2$$

$$0 \leq \phi \leq 2\pi$$

The routine is called each time a new ray is created and should provide values of θ and ϕ that correspond to some desired probability distribution.

An example would be to provide a Lambertion distribution. In this case the subroutine would generate a random ϕ and a random $\cos^2 \theta$. From $\cos^2 \theta$, θ would then be found.

3.1.2.4 Wavelength Dependent Fraction of Reflection

When the fraction of a ray's intensity to be reflected is dependent on the wavelength, a subroutine must be provided to give the fraction for each wavelength. The name of the subroutine must be of the form:

REFLXX

where XX is the reflection number of the boundary.

There are two separate cases that may be considered.

1. Fraction dependent on wavelength only
2. Fraction dependent on wavelength and angle of incidence.

In case 1 the argument list is:

```
SUBROUTINE REFLXX(XLAM,FMAX,TSTG,DUM)
```

where

XLAM	=	name of wavelength array
FMAX	=	number of wavelengths (integer)
TSTG	=	array for storing fractions of reflection
DUM	=	dummy argument.

In this case the routine is called at the beginning of the problem and the information is stored for later use. The subroutine must determine and store the fractions of reflection into the array:

TSTG(F),F=1,FMAX.

In case 2 the argument list is:

```
SUBROUTINE REFLXX(XLAM,FMAX,TSTG,COSGAM)
```

where

XLAM	=	name of wavelength array
FMAX	=	number of wavelengths (integer)
TSTG	=	array for storing fractions
COSGAM	=	the cos of the angle of incidence.

In this case the subroutine is called when an intersection occurs and must calculate the fraction to be reflected for each wavelength for the particular angle of incidence indicated. These fractions are then stored into the array

TSTG(F),F=1,FMAX

3.2 INPUT

Input to the ZAP code is in the form of data cards. Special keypunch forms have been designed for each of the various types of input cards, with the exception of the general input which uses a standard FORTRAN data sheet.

The entries use a combination of integer, real and alphanumeric formats. In the case of real and integer input, either a blank or zero may be entered if the number is zero.

All directional cosines entered are checked by the code and the sum of the squares of the three directional cosines must be within the range of 1.0 ± 10^{-3}. If they are not, the program will terminate execution with a debug print.

Care must be taken that no plane passes through the origin. If this happens, the program will terminate execution.

Wherever possible default conditions have been provided so that if the number is blank or zero, the default number is used.

3.2.1 General Input (three cards)

Card #1 - 72 character comment or title card

Card #2

Entry Number	Description	Format	Columns
1)	FRAC = Base fraction. When a ray intensity drops below this fraction of its initial intensity, Russian Roulette is played. Default number = .5.	E12.4	1-12
2)	DZ = Distance along Z axis between planes of continuity. If no planes of continuity exist, this number is ignored.	E12.4	13-24
3)	WAVMIN = minimum wavelength. (May be omitted for single wavelength.)	E12.4	25-36
4)	WAVMAX = maximum wavelength. If there is only one wavelength, this number is ignored.	E12.4	37-48

Card #3

Entry Number	Description	Format	Columns
1)	FMAX = Number of wavelengths	I6	1-6
2)	IOPRNT = Option for printing each ray created. 0 = no 1 = yes	I6	7-12
3)	IDEBUG = Option for debug prints. 0 = no 1 = yes	I6	13-18
4)	IR = starting random integer. Default = 1.	I16	19-34

No blank card following general input cards.

3.2.2 Reflection Data

For each special reflection a reflection data card must be provided. The reflection number must be greater than ten, since reflection numbers 1-10 are reserved for built-in reflection types.

Entry Number	Description	Format	Columns
1)	Reflection number (greater than ten).	Integer	2-4
2)	Reflection type (left justified). CONST‸ = Constant reflection (fraction reflected will be input). FUNCT‸ = Function of the form: fraction reflected = 1.0-A(cos θ)^2 where A is input and cos θ is the angle made by the impending ray with the normal to the surface. TABLE‸ = An input table of ten fractions which indicate the amount reflected for different angles with the normal. Angles are from 0° to 90° in 10° intervals. DIFFUS = Diffuse reflection. Fraction to be reflected is input. WAVCAL = Reflection dependent on wavelength. The fraction of each wavelength to be reflected is calcu- as a function of the wavelength and the angle of incidence. A subroutine REFLXX must be provided where XX is the reflection number. Example, reflection number 12 means that the subroutine is REFL12. (See section on User Subroutines for details.) WAVINP = Reflection dependent on wavelength only. A subroutine named REFLXX must be provided where XX is the reflection number. This subroutine is called immediately at the time this card is read, and fills an array with wavelength dependent fractions of reflection to be used later. (See section on User Subroutines.)	Alpha	6-11

3)	For CONST load fraction to be reflected. For FUNCT load value for A. For DIFFUS load fraction to be reflected. For TABLE load fraction for 0°. For WAVCAL or WAVINP this ~~entry~~ is ignored.	Real	13-17
4-12	For TABLE load fractions to be reflected for angles 10°-90°. Blanks for other reflection types.	Real	19-71

A blank card must follow the last reflection data card. If no reflection data was loaded, the blank is still required.

3.2.3 Material Data

For each material a material data card must be provided.

Entry Number	Description	Format	Columns
1)	Material number	Integer	2-4
2)	Name of routine to generate absorption coefficients as a function of wavelength. (See section on User Routines). If this is a single wavelength run, this entry is ignored.	Alpha	6-11
3)	Absorption coefficient (length^{-1}) If an input routine was specified above, this number is ignored.	Real	13-18
4)	Refractive index (must be non-zero)	Real	20-25
5)	Lazing wavelength (for multiple wavelength runs only). This is an optional input value.	Real	27-32
6)	39 character description to be printed	Alpha	34-72

A blank card must follow the last material data card.

3.2.4 Boundary Data

For each boundary a boundary data card must be provided. The form of the data on the card depends on the geometry type.

Entry Number	Description	Format	Columns
1)	Boundary number	Integer	2-4
2)	Reflection number	Integer	6-8
	1 = total transmission, no refraction		
	2 = total reflection. May or may not represent boundary of symmetry.		
	3 = Fresnel's reflection for dielectrics.		
	4 = Top boundary of continuity.		
	5 = Bottom boundary of continuity.		
	6-10 = Reserved for further built-in reflection types.		
	11-50 = Special reflection types defined on reflection data sheet.		
3)	Geometry type (left justified in columns provided on data sheet).	Alpha	10-15
	CYLIND = cylinder		
	PLANE^ = plane		
	CONIC^ = conic		
	SPHERE = sphere		
	CONE^^ = half-cone with axis parallel to Z axis		
	PARAB^ = paraboloid of revolution with axis parallel to Z axis.		
	HYPERB = hyperboloid of revolution with axis parallel to the Z axis.		
	ELLIPS^ = ellipsoid of revolution whose axis is parallel to the Z axis.		
	HELIX = helical tube with axis parallel to the Z axis		

Boundary Data (continued)

Entry Number	Description	Format	Columns
4-11)	Parameters for the particular geometry type being described:	Real	
	PLANE:		
	4) α Directional cosines for the normal to the plane. Normal must point from origin toward plane.		17-22
	5) β		24-29
	6) γ		31-36
	7) X Coordinates of a point on the plane.		38-43
	8) Y		45-50
	9) Z		52-57
	10-11)--Not used		
	CYLIND:		
	4) α Directional cosines for cylindrical axis.		17-22
	5) β		24-29
	6) γ		31-36
	7) X Coordinates of a point on the cylindrical axis.		38-43
	8) Y		45-50
	9) Z		52-57
	10) R =Radius of cylinder		59-64
	11) -- Not used		
	CONIC:		
	4) α Directional cosines for axis.		17-22
	5) β		24-29
	6) X_0 Coordinates of focus.		31-36
	7) Y_0		38-43
	8) X_1 Coordinates of two points on the conic surface. These two points must not be symmetrical with respect to the axis.		45-50
	9) Y_1		52-57
	10) X_2		59-64
	11) Y_2		66-71
	SPHERE:		
	4) X_c Coordinates of center of sphere		17-22
	5) Y_c		24-29
	6) Z_c		31-36
	7) R = Radius of sphere		33-43
	9-11) Not used		

Boundary Data (continued)

Entry Number	Description	Format	Columns
	CONE:		
	4) X_v Coordinates of the vertex		17-22
	5) Y_v		24-29
	6) Z_v		31-36
	7) X Coordinates of a point on the surface of the half-cone to be considered.		38-43
	8) Y		45-50
	9) Z		52-57
	10-11) -- Not used.		
	PARAB:		
	4) X_v Coordinates of the vertex		17-22
	5) Y_v		24-29
	6) Z_v		31-36
	7) Z_f = Z coordinate of the focus		
	HYPERB:		
	4) X_v Coordinates of vertex for sheet to be considered.		17-22
	5) Y_v		24-29
	6) Z_v		31-36
	7) X Coordinates of a point on the surface. This point may be on either sheet.		38-43
	8) Y		45-50
	9) Z		52-57
	10) Z_f = Z coordinate of focus for sheet to be considered.		59-64
	11) -- Not used.		
	ELLIPS:		
	4) X_v Coordinates of vertex		17-22
	5) Y_v		24-29
	6) Z_v		31-36
	7) X Coordinates of a point on the surface of the ellipsoid.		38-43
	8) Y		45-50
	9) Z		52-57

Boundary Data (continued)

Entry Number	Description	Format	Columns
	ELLIPS (continued)		
	10) Z_f = Z-coordinate of the focus nearest the chosen vertex.		59-64
	11) -- Not used.		
	Restriction: $A \leq B \leq C$ where $A = 2(Z-Z_v)(Z_f-Z_v) - (Z-Z_v)^2$; $B = (X-X_v)^2 + (Y-Y_v)^2$; $C = 4(Z_f-Z_v)(Z-Z_v)$		
	HELIX		
	4) X_h 5) Y_h 6) Z_h Coordinates of a point on the helical axis. The nearest point on the helical wire is assumed to be in the positive X direction from this point.		17-22, 24-29, 31-36
	7) κ = Parameter associated with distance between consecutive coils. $D = 2\pi\kappa$. If $\kappa<0$, coil is lefthanded.		38-43
	8) ρ = radius from axis to helical wire.		45-50
	9) a = radius of tube.		52-57
	10=11) Not used.		

3.2.5 Segment Data

For each segment, a segment data card must be provided.

Entry Number	Description	Format	Columns
1)	Segment number	Integer	2-4
2)	Material number	Integer	6-8
3-13)	Boundary numbers indicating the confining boundaries of the segment. A positive boundary number indicates the origin side of a plane or inside of other geometries. A negative boundary indicates the non-origin side of a plane, or the outside of other geometries.	Integer	10-63
14)	Segment volume (if known).	Real	65-71

A blank card must follow the last segment data card.

3.2.6 Structure Data

For each mother-daughter relationship, a structure data card must be provided.

Entry Number	Description	Format	Columns
1)	Mother segment	Integer	2-4
2-18)	Daughter segments	Integer	6-68

A blank card must follow the last structure data card.

3.2.7 Lamp Data

For each lamp type a lamp data card must be loaded. This data describes primarily the method to be used for creating rays. Many different sources may refer to the same lamp type.

Entry Number	Description	Format	Columns
1)	Lamp number	Integer	2-4
2)	Lamp type (left justified) VOLUME = volume source OUTSUR = cylindrical surface source with rays directed outward from the surface. INNSUR = cylindrical surface source with rays directed inward from the surface. RAYINP = directional cosines and starting coordinates are input for each ray.	Alpha	6-11
3)	Name of routine to be used for generating intensity as a function of wavelength. This routine will have a name INTENX where X is a number from 1 to 9 (see user routines) and must be provided by the user. If this is a single wavelength run, this entry is ignored.	Alpha	13-18
4)	Name of routine to be used for calculating the angle with the normal for rays created if this is a surface source. If not a surface source this entry is ignored. See user routines for description of this routine.	Alpha	20-25
5)	Intensity of rays if this is a single wavelength run. If multiple wavelength, this entry is ignored.	Real	27-37

A blank card must follow the last Lamp Data card.

3.2.8 Source Data

A source data card must be provided for each source in the problem.

Entry Number	Description	Format	Columns
1)	Source number	Integer	2-4
2)	Segment number or boundary number of source. If the lamp type designated is for a volume source, load a segment number. If the lamp type designated is for a surface source, load a boundary number.	Integer	6-8
3)	Lamp number - refers to a lamp data card.	Integer	10-12
4)	Number of rays for this source.	Integer	14-17
5-10)	Parameters which depend on the particular lamp type designated. VOLUME: 5) XMIN 6) XMAX 7) YMIN 8) YMAX 9) ZMIN 10) ZMAX Minimum and maximum Values of X,Y and Z which describe a rectangle within which the source segment is containcd. INNSUR or OUTSUR: 5-8) Blank 9) ZMIN 10) ZMAX Minimum and maximum values of Z for creating rays. RAYINP: Entries 5-10) are ignored.	Real	

For RAYINP, this card is immediately followed by Ray data cards for the number of rays specified above.

A blank card must follow the last Source Data card.

3.2.9 Ray Data

If rays are to be input individually, one data card must be input for each ray to be created. Use source data sheets.

Entry Number	Description	Format	Columns
1-4)	Blank		
5)	α } Directional cosines of ray	Real	19-25
6)	β		27-33
7)	γ		35-41
8)	X } Starting point of ray	Real	43-49
9)	Y		51-57
10)	Z		59-65

3.2.10 Test Data

Test data cards are used to test the geometrical setup for errors. This consists of referencing a segment number and indicating that a specified point lies either inside or outside of the segment. The point is then tested to see if it does lie on the proper side of the segment. As many sets of test data as desired may be loaded.

Entry Number	Description	Format	Columns
1)	JTEST = Segment number to be tested. if JTEST>0, point should lie inside segment. If JTEST<0, point should lie outside of segment.	Integer	1-6
2)	IOP = Option for testing to see if point lies within the confining boundaries of the segment, or to see if the point lies within this segment rather than some other segment.	Integer	7-12
	IOP = 0, Test segment boundaries only		
	IOP = 1, Determine which segment contains the point and determine if it is the desired segment.		
3)	X = Coordinates of the test point	Real	13-24
4)	Y = Coordinates of the test point	Real	25-36
5)	Z = Coordinates of the test point	Real	37-48

3.2.11 Plot Data

Each plot data card indicates a rectangular area within a plane that slices through the system. This plane may be at any desired orientation. The geometric boundaries sliced by the plane within the rectangular area are then plotted. The only restriction is that the rectangular area must be completely contained within the overall mother region (Region #1). This is no real restriction since the overall mother region may be made as large as desired without affecting the speed or accuracy of the program.

Entry Number		Description	Format	Columns
1)	X_0	Coordinates of the point to be used for the lower left-hand corner of the plotting area.	Real	1-8
2)	Y_0		Real	9-16
3)	Z_0		Real	17-24
4)	X_1	Coordinates of the point to be used for the lower right-hand corner of the plotting area.	Real	25-32
5)	Y_1		Real	33-40
6)	Z_1		Real	41-48
7)	X_2'	Coordinates of a point that lies somewhere along the top line of the plotting area.	Real	49-56
8)	Y_2'		Real	57-64
9)	Z_2'		Real	65-72

A blank card must follow the last of the plot data cards.

3.3 OUTPUT

Output from the ZAP code consists of printer plots of various cuts through the geometry and printed summaries of the energy deposition for each segment and for each material.

Under the heading SEGMENT RESULTS the following quantities are printed for each segment:

1. Mother segment number = mother of the segment being considered.
2. Segment number.
3. Material number in segment.
4. Total Energy = Sum of energy deposited in segment.
5. Scaled Energy = Sum of energy scaled by lasing wavelength.
6. Energy per unit volume.
7. Percent total energy = The percent of the total energy in the system that is in this segment.
8. Percent error = probable statistical percent error. (See Section 2.5.2)
9. Number of legs = actual number of ray legs traced through segment.
10. Number of rays = number of different rays traced through segment, even though each ray may have had several legs passing through the segment.

Under the heading MATERIAL results the following quantities are printed:

1. Total absorbed energy = sum of segment energies.
2. Total source energy - sum of initial ray intensities.
3. Total number of rays.
4. Final random integer = Random integer that could be used to continue the run without changing the random number sequence.

For each material the following quantities are printed:

1. Material number
2. Material volume = sum of volumes of segments containing material.
3. Total energy = sum of energies of segments containing material.
4. Scaled energy = sum of scaled segment energies for material.
5. Energy per unit volume.
6. Percent of total energy = The percent of the total energy in the system that is in this material.
7. Percent error = Probable statistical percent error. (See Section 2.5.2)
8. Number of rays = number of different rays that passed through the material.

3.4 SAMPLE PROBLEM #1

The first sample problem consists of a cylindrical lamp and a cylindrical laser rod encased in an elliptic laser cavity (Fig. 3.1). The area of interest is chosen to be in the body of the system so that end conditions are ignored. In this case each end is considered to be a boundary of symmetry (a simple boundary of total reflection).

A single wavelength is considered and parameters such as absorption coefficients and refractive indices are not intended to be physically real but were chosen arbitrarily for demonstration purposes.

The laser system is encased in a 20 cm sphere that is considered to be the overall Mother segment (segment #1). The area inside the cavity was chosen to be segment #2 and is a mother containing two daughters. These daughters are respectively, segment #3 which is the cylindrical lamp and segment #4 which is the cylindrical laser rod. The laser rod is a mother and has daughters #5 and #6 which are simply the front and back half of the laser rod. Note that the area of segment #4 is completely filled by segments #5 and #6 so that segment #4 has no actual volume of its own.

The material outside of the cavity is chosen to be material #1, the air inside the cavity is material #2, the lamp is composed of material #3 and the laser rod consists of material #4. These material numbers appear in their proper places in the printer plots (3.2 through 3.6).

Boundary #1 is the sphere encasing the system. Boundary #2 is the elliptic cylinder that represents the cavity wall and is chosen to be a boundary of constant reflection with 90% reflection and 10% transmission. Boundaries #3 and #4 are cylinders defining the lamp and laser rod respectively

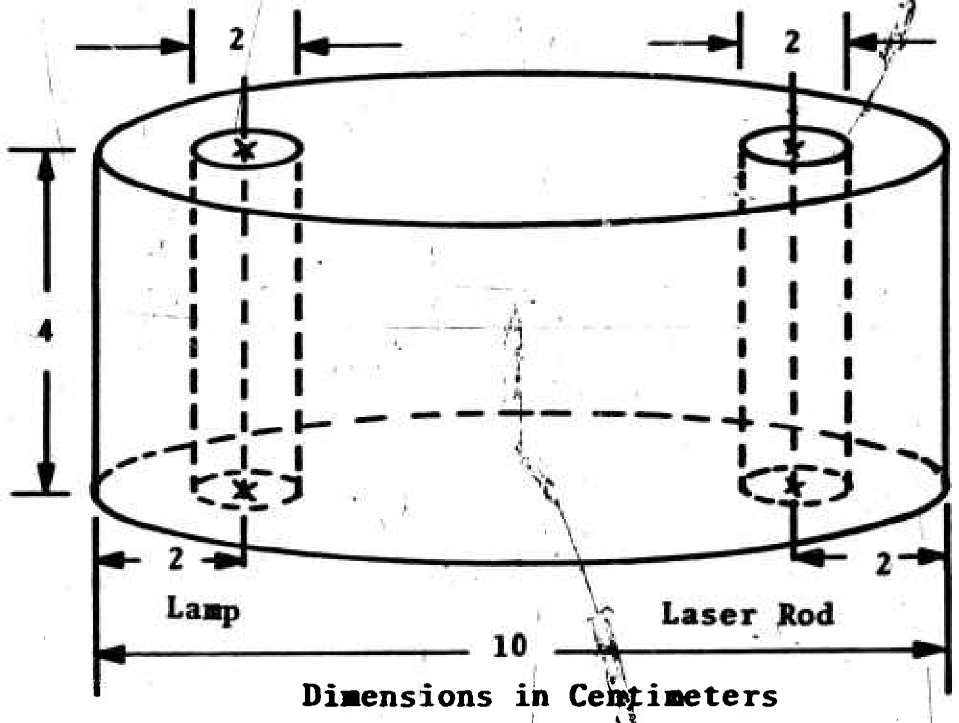


Figure 3.1 A simple laser cavity used for sample problem #1.

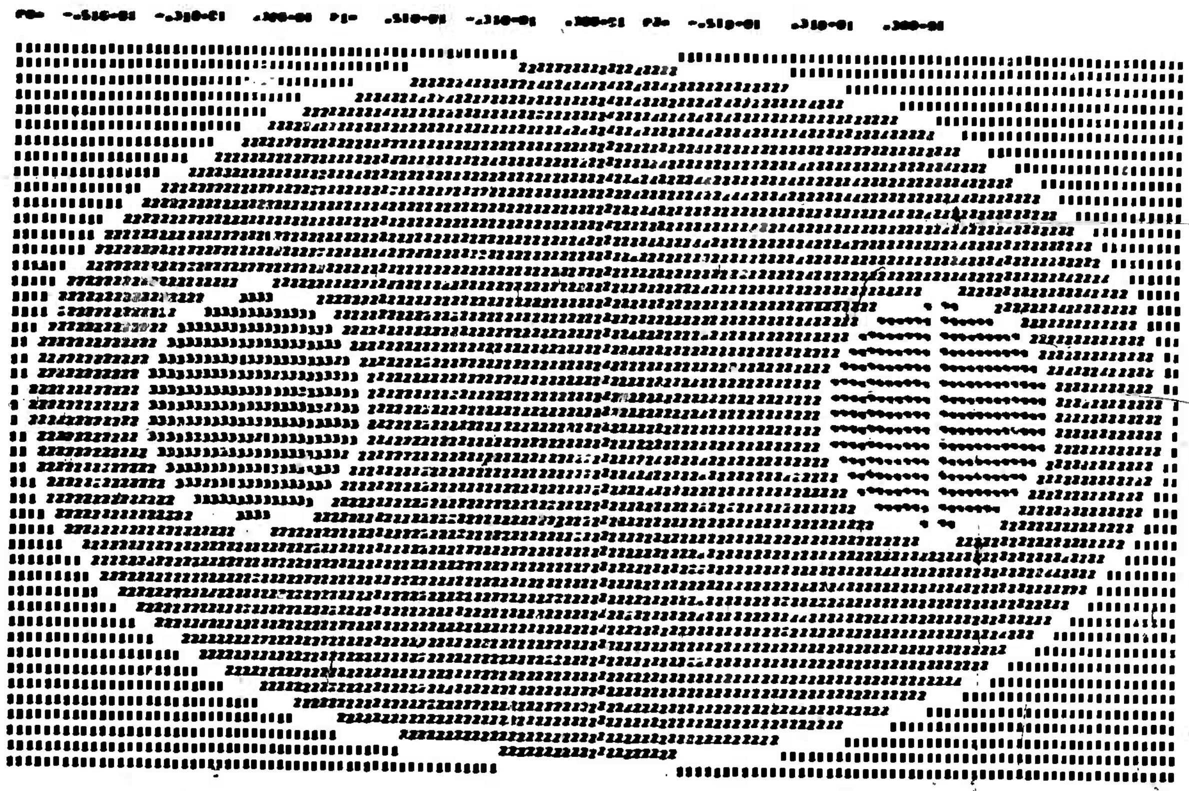


Figure 3.2 Top view of laser system used in sample problem #1.

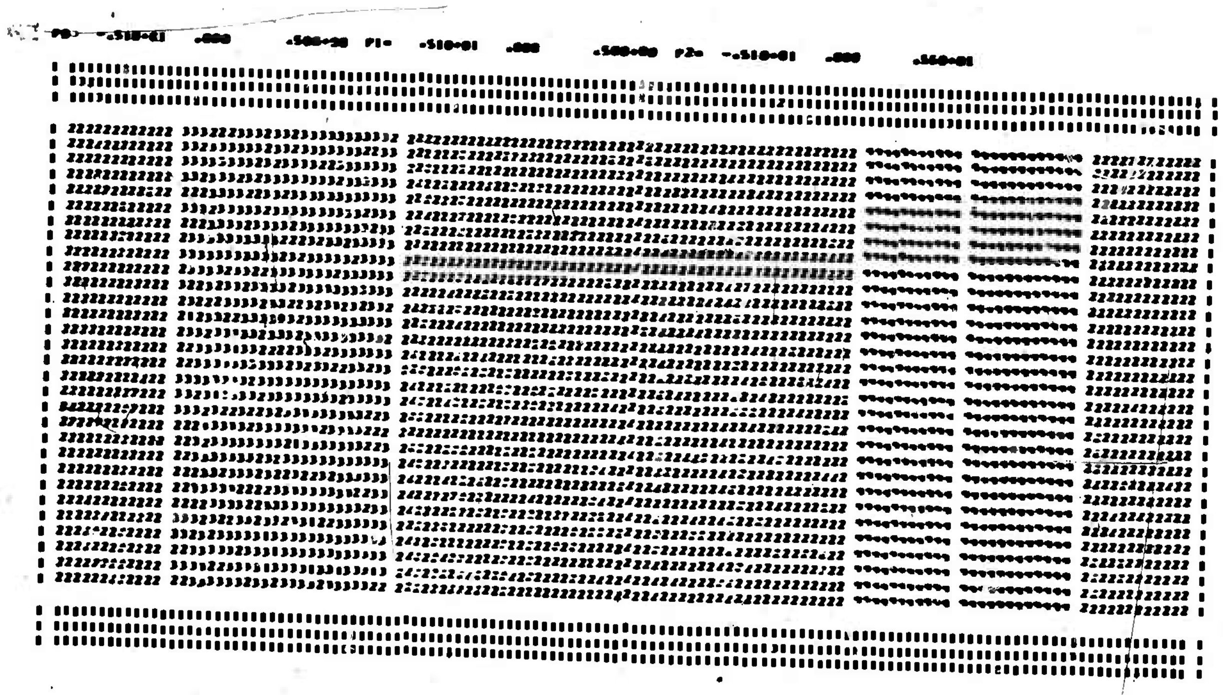

P0= -.510+01 .000 .500+38 P1= .510+01 .000 .500+00 P2= -.510+01 .000 .560+01

Figure 3.3 Side view of laser system used in sample problem #1.

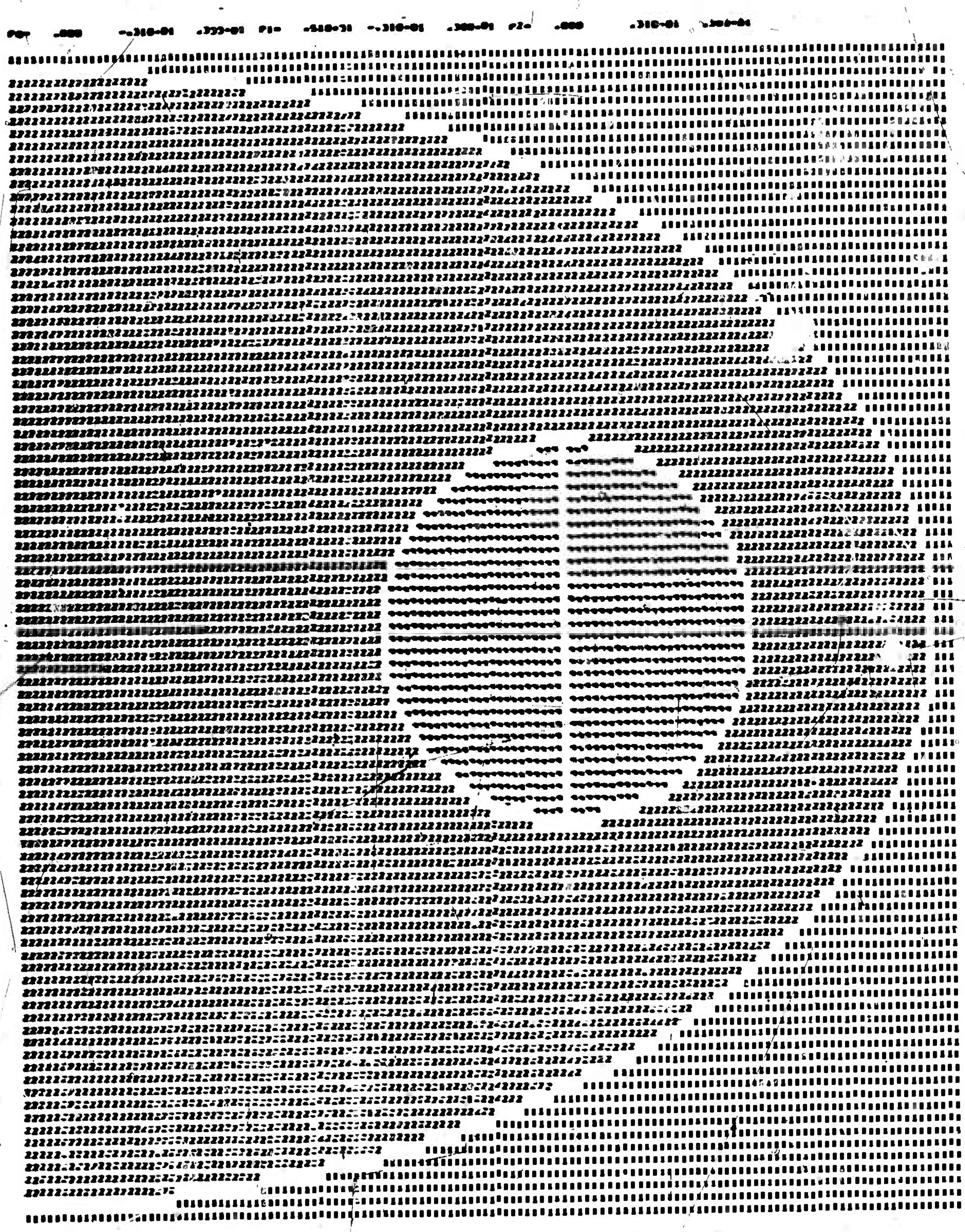


Fig. 3.4 Top view of right half of laser system used in sample problem #1.

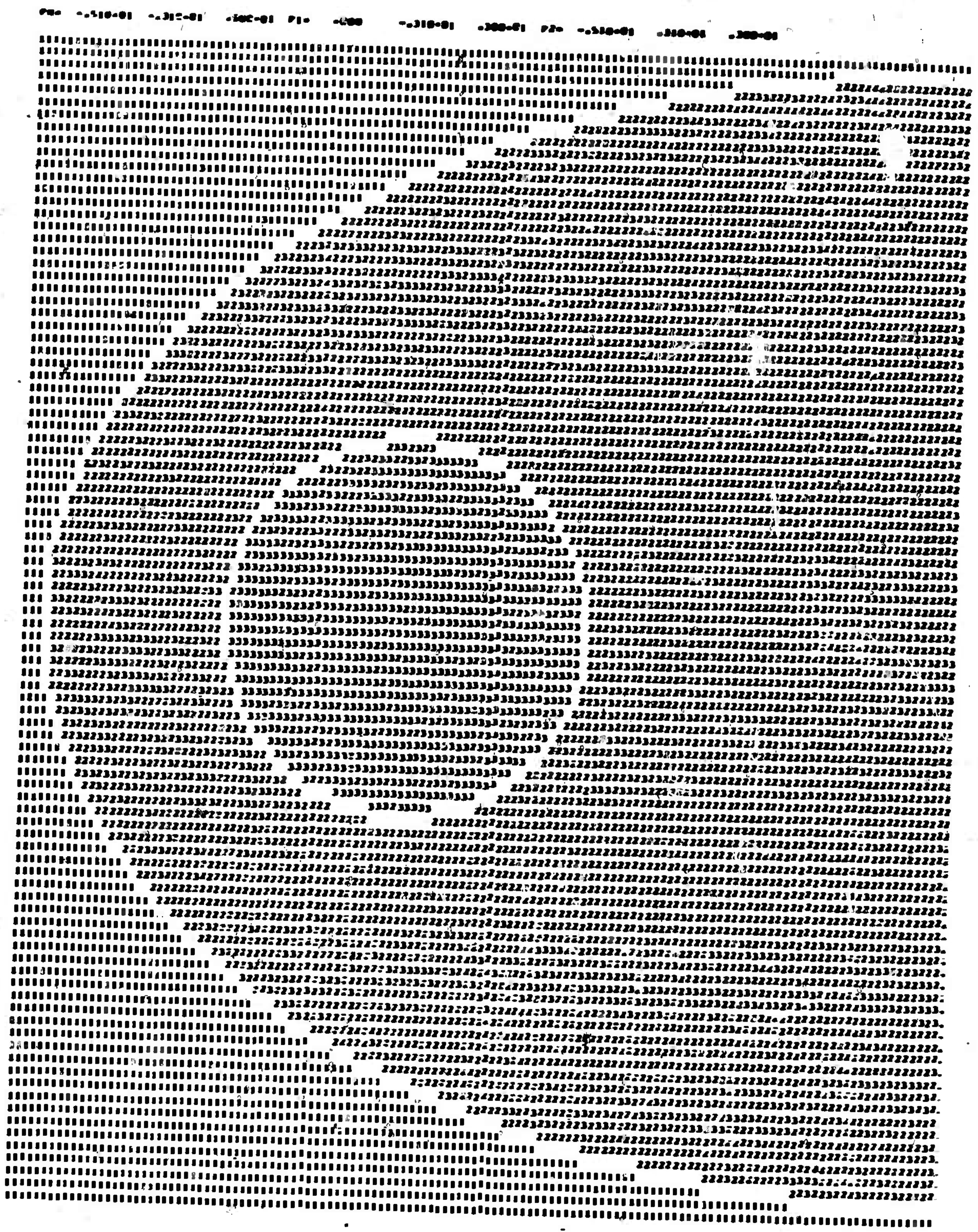

P0= -.510-01 -.312-01 .100-01 P1= .000 -.310-01 .300-01 P2= -.510-01 .310+00 .300-01

Fig. 3.5 Top view of left half of laser system used in sample problem #1.

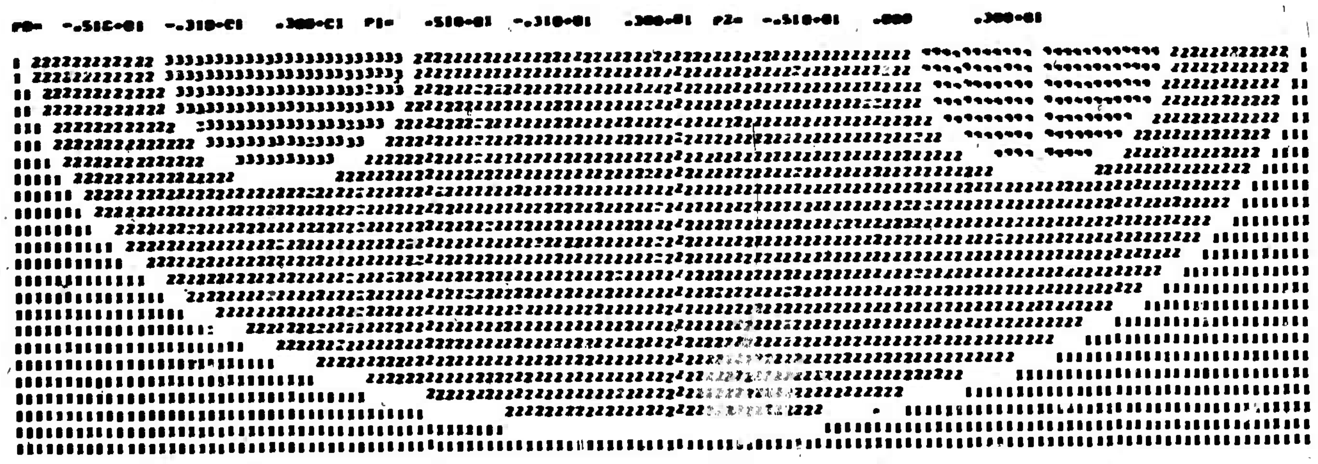

P0= -.510+01 -.310+01 .300+01 P1= .510+01 -.310+01 .300+01 P2= -.510+01 .000 .300+01

Figure 3.6 Top view of lower half of laser system used in sample problem #1.

and allow Fresnel's reflection. The end planes are planes of symmetry (total reflection) and are boundaries #5 and #6. The plane that divides the laser rod into two segments is boundary #7 and is a dummy boundary.

The lamp (segment #3) is a volume source that emits rays with an intensity of 1.0. Only 100 rays were emitted for this sample run.

A listing of the input cards used and a listing of the results are given below.

INPUT DATA

```
SAMPLE PROBLEM NUMBER-1
.5          0.0          1.0          0.0                                                    01
    1     0     0                                                                           02
  11 CONST  .9                                                                              03
                                                                                            04
  1         1000.0 2.0                                                                      05
  2         .1     1.0          METAL AROUND SYSTEM
                                FLUID                                                       06
  3         .1     1.5                                                                      07
  4         .1     1.7    5.0   LAMP
                                LASER ROD                                                   08
  1    2 SPHERE 0.0    0.0    0.0    20.0                                                   09
  2   11 CONIC  1.0    0.0   -4.0    0.0                                                    10
  3    3 CYLIND 0.0    0.0    1.0   -3.0   -5.0    0.0    0.0    3.0                        11
  4    3 CYLIND 0.0    0.0    1.0   -3.0    0.0    0.0    1.0                               12
  5    2 PLANE  0.0    0.0    1.0    3.5    0.0    0.0    1.0                               13
  6    2 PLANE  0.0    0.0    1.0    0.0    0.0    1.0                                      14
  7    1 PLANE  1.0    0.0    1.0    0.0    0.0    5.0                                      15
                              0.0    3.0    0.0    0.0                                      16
  1    1    1                                                                               17
  2    2    2   -5    6                                                                     18
  3    3    3   -5    6                                                                     19
  4    4    4   -5    6                                                                     20
  5    4    4    7   -5    5                                                                21
  6    4    4   -7   -5    6                                                                22
                                                                                            23
  1    2                                                                                    24
  2    3    4                                                                               25
  4    5    6                                                                               26
                                                                                            27
 1 VOLUME                                                                                   28
                       1.0                                                                  29
 1    3    1  100 -4.0    -2.0    -1.0    1.0    1.0    5.0                                 30
                                                                                            31
  1       1-5.0          0.0           6.5                                                  32
  2       10.0           0.0           3.0                                                  33
  3       1-3.5          0.0           3.0                                                  34
  6       13.5           0.0           3.0                                                  35
  2       00.0           0.0           3.0                                                  36
                                                                                            37
-5.1    -3.1    3.0     5.1    -3.1    3.0    -5.1    3.1    3.0                            38
-5.1     0.0    .5      5.1     0.0    .5     -5.1    0.0    5.5                            39
 0.0    -3.1    3.0     5.1    -3.1    3.0     0.0    3.1    3.0                            40
-5.1    -3.1    3.0     0.0    -3.1    3.0    -5.1    3.1    3.0                            41
-5.1    -3.1    3.0     5.1    -3.1    3.0    -5.1    0.0    3.0                            42
                                                                                            43
                                                                                            44
                                                                                            45
```

RESULTS

```
GENERAL INPUT FOR ZAP

SAMPLE PROBLEM NUMBER=1
ROULETTE FRACTION=      .5000+00
DISTANCE BETWEEN CONTINUITIVE BOUNDARIES=     .0000
MINIMUM WAVELENGTH=      .1000+01
MAXIMUM WAVELENGTH=      .0000
NUMBER OF WAVELENGTHS=       1
RAY PRINT OPTION=      0
DEBUG PRINT OPTION=      0
STARTING RANDOM INTEGER=                    1



                                      REFLECTION DATA

REFLECTION      TYPE
   NUMBER

        11      CONST      .9000     .0000     .0000     .0000     .0000     .0000     .0000     .0000     .0000     .0000



                                      MATERIAL DATA

MATERIAL   INPUT      ABSORPTION      REFRACTIVE      LASING       DESCRIPTION
  NUMBER  ROUTINE     COEFFICIENT       INDEX       WAVELENGTH

       1              1000.000000      2.000000      .000000       METAL AROUND SYSTEM
       2                  .100000      1.000000      .000000       FLUID
       3                  .100000      1.500000      .000000       LAMP
       4                  .100000      1.700000     5.000000       LASER ROD
```

RESULTS

```
                                                    BOUNDARY DATA

BOUND  REFL   BOUND   ALPHA    BETA   GAMMA       X        Y        Z       X2       Y2       X3       Y3      DIS      ECC
 NUMB  NUMB    TYPE

    1     2  SPHERE                             .000     .000     .000                                        20.000
    2    11   CONIC   1.000    .000          -4.000     .000              -5.000     .000     .000    3.060    2.250     .800
    3     3  CYLIND    .000    .000   1.000  -3.000     .000     .000                                         1.000
    4     3  CYLIND    .000    .000   1.000   3.000     .000     .000                                         1.000
    5     2   PLANE    .000    .000   1.000    .000     .000    1.000                                         1.000
    6     2   PLANE    .000    .000   1.000    .000     .000    5.000                                         5.000
    7     1   PLANE   1.000    .000    .000   3.000     .000     .000                                         3.000


                                                    SEGMENT DATA

SEGMENT  MATERIAL      CONFINING BOUNDARIES                                                           VOLUME
 NUMBER    NUMBER

      1         1      1    0    0    0    0    0    0    0    0    0    0                          .000000
      2         2      2   -5    6    0    0    0    0    0    0    0    0                          .000000
      3         3      3   -5    6    0    0    0    0    0    0    0    0                          .000000
      4         4      4   -5    6    0    0    0    0    0    0    0    0                          .000000
      5         4      4    7   -5    6    0    0    0    0    0    0    0                          .000000
      6         4      4   -7   -5    6    0    0    0    0    0    0    0                          .000000


                                                    STRUCTURE DATA

MOTHER          DAUGHTER SEGMENTS
SEGMENT

      1          2
      2          3    4
      4          5    6
```

RESULTS

```
                                                        LAMP DATA
LAMP       LAMP   INTENSITY      ANGLE   INTENSITY
NUMBER     TYPE     ROUTINE    ROUTINE
     1   VOLUME                           .1000+01


                                                        SOURCE DATA
SOURCE  SEGMENT  BOUNDARY      LAMP   NUMBER    GEOMETRIC SOURCE DATA
NUMBER   NUMBER    NUMBER    NUMBER  OF RAYS
     1        3         0         1      100    -4.00000    -2.00000    -1.00000    1.00000    1.00000    8.00000


                                                        TEST DATA
SEGMENT  OPTION             X             Y             Z
      1       1    -.5000+01     .0000         .6500+01
      2       1     .0000        .0000         .3000+01
      3       1    -.3500+01     .0000         .3000+01
      6       1     .3500+01     .0000         .3000+01
      2       0     .0000        .0000         .3000+01
```

RESULTS

```
                                                    SEGMENT RESULTS
 MOTHER    SEGMENT  MATERIAL        TOTAL       SCALED        ENERGY    PERCENT    PERCENT    NUMBER    NUMBER
 SEGMENT   NUMBER     NUMBER       ENERGY       ENERGY      PER UNIT      TOTAL      ERROR        OF        OF
 NUMBER                                                        VOLUME     ENERGY                  LEGS      RAYS
      1
                 2          2    .3065+02      .0000         .0000      31.590     20.893       191        39
      2
                 3          3    .6063+02      .0000         .0000      62.485      9.138       574       100
                 4          4    .0000         .0000         .0000        .000     ......         0         0
      4
                 5          4    .1679+01      .3389+00      .0000       1.731     38.870        22        10
                 6          4    .1487+01      .2918+00      .0000       1.602     35.528        20        12


                                                    MATERIAL RESULTS

TOTAL ABSORBED ENERGY=    9.7029+01
TOTAL SOURCE ENERGY  =    1.0000+02
TOTAL NUMBER OF RAYS =          100
FINAL RANDOM INTEGER =   8328333409

     MATERIAL     MATERIAL        TOTAL      SCALED   ENERGY PER     PERCENT OF       PERCENT        NUMBER
       NUMBER       VOLUME       ENERGY      ENERGY   UNIT VOLUME  TOTAL ENERGY         ERROR       OF RAYS
            1        .0000    .2610+01       .0000        .0000          2.689        49.233             4
            2        .0000    .3065+02       .0000        .0000         31.590        20.786            39
            3        .0000    .6063+02       .0000        .0000         62.483         9.092           100
            4        .0000    .3137+01    .6274+00        .0000          3.233        38.626            14

8FIN
```

3.5 SAMPLE PROBLEM #2

3.5.1 Introduction

In order to demonstrate the actual use of ZAP, the simple laser system shown in Figure 3.7 will be analyzed. In this laser, a spherical metal reflector contains a xenon flashlamp and a neodymium-doped glass laser rod; the lamp and rod are held at their ends by cylindrical holders. When the lamp is pulsed, power is produced throughout the volume of xenon; the amount produced depends on wavelength. The power travels through the plasma to the wall of the lamp (some is absorbed on the way), refracts through the wall, and enters the reflector volume. There the power bounces off the walls and other surfaces, travels through the glass laser rod and reflector surfaces. We are interested in the fractions of the initial power which end up in the rod, lamp, and walls, and also in the power distribution in the laser rod.

3.5.2 Initial Analysis of the Geometry

We can use the symmetry of the laser assembly to improve the statistics of our results, by putting perfectly reflecting planes in the two planes of symmetry (see Figure 3.7). This in effect gives four times as many rays per unit of run time (we could get the same result without the planes and their time-losing reflection by adding together the depositions in symmetrically equivalent volumes, but the computer time lost to the reflections is cheap compared to the human time gained in not adding numbers). The introduction of the symmetry planes reduces the problem to a quadrant of a sphere, as shown in Figure 3.8. The decomposition of the quadrant into successive mother and daughter segments is also shown in Figure 3.8. (The rod is divided into eight segments of essentially equal volume so that the energy distribution in

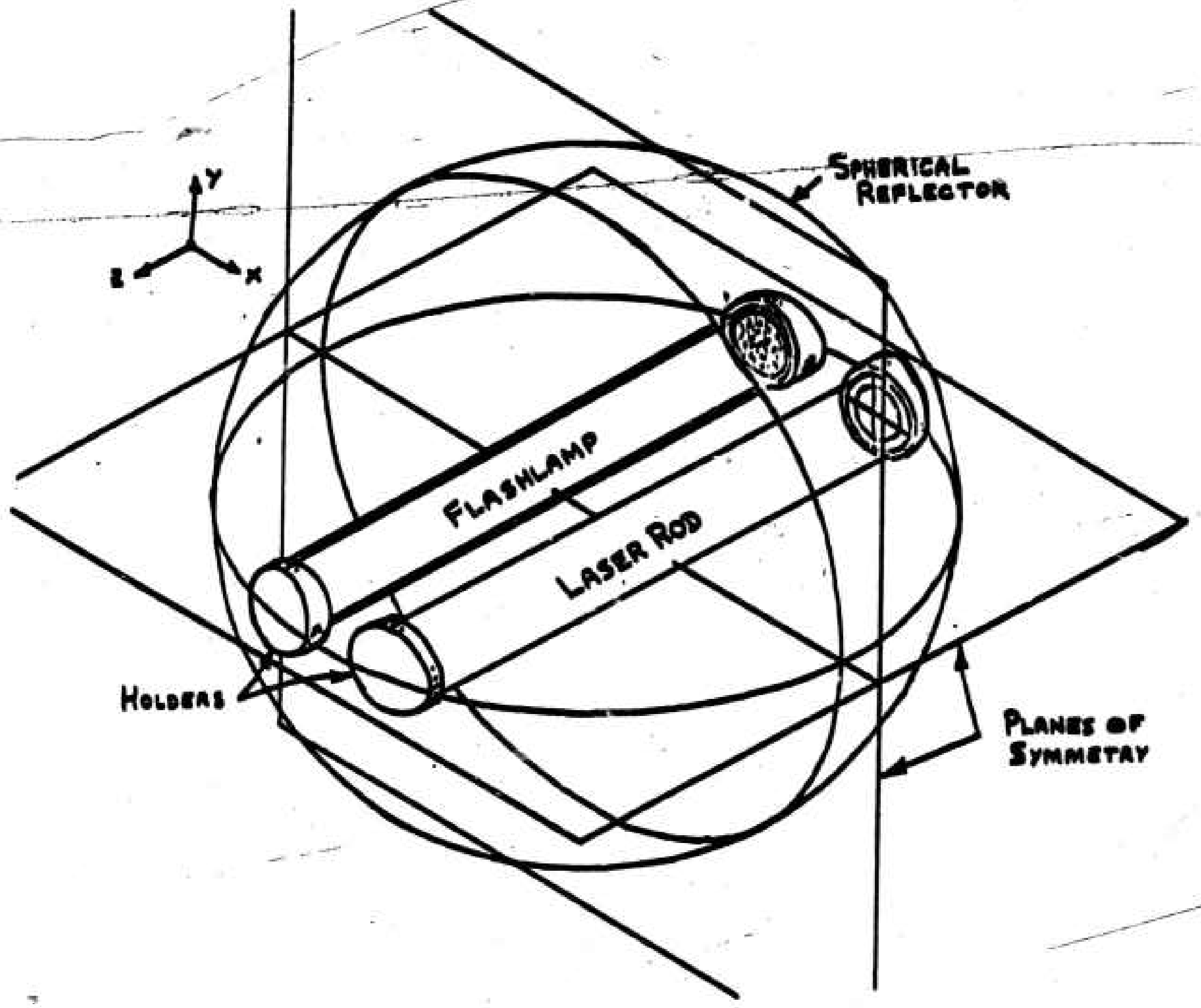


Figure 3.7 General view of laser analyzed. A 1 cm diameter xenon flashlamp pumps a 1 cm diameter Nd^{3+} - doped glass rod. Both are 10 cm long, and are enclosed in an 11 cm diameter spherical reflector. Cylindrical end pieces hold the rod and lamp.

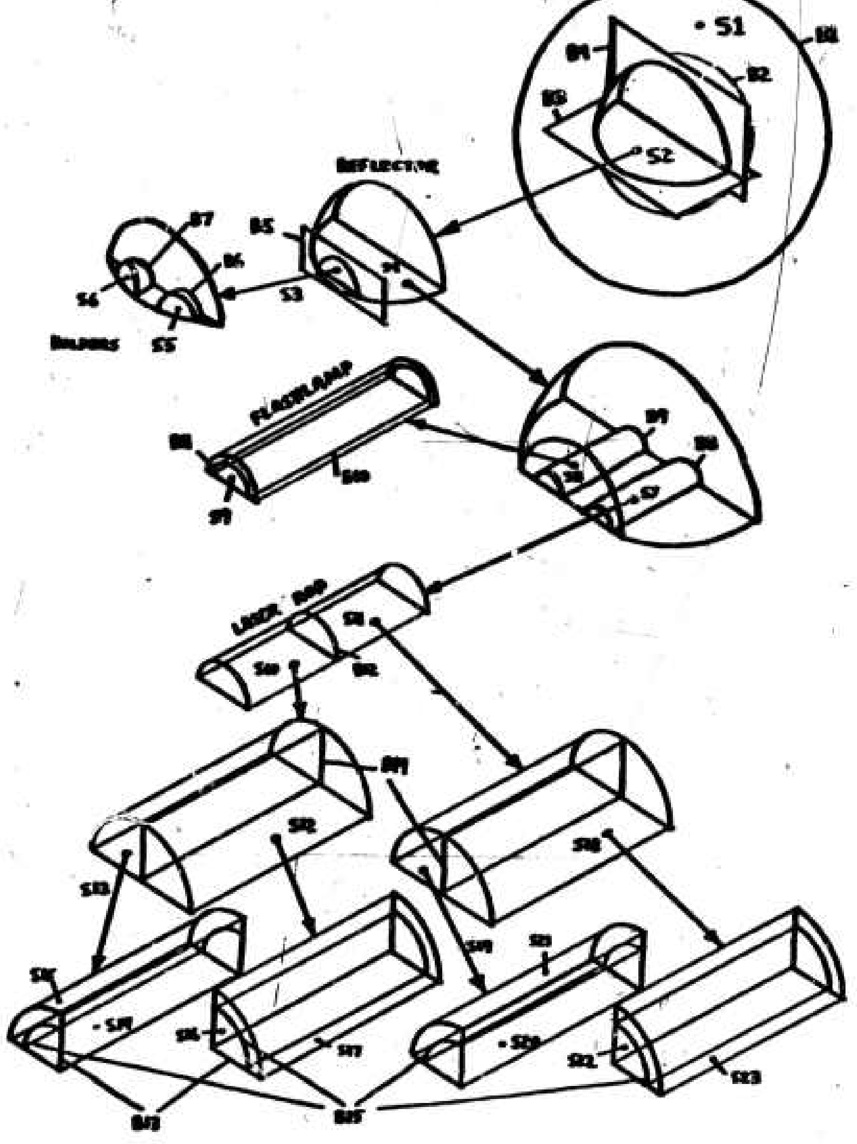


Figure 3.8 The decomposition of the laser assembly for ZAP input. Boundaries (indicated by numbers starting with B) are chosen so that all needed segments (indicated by numbers starting with S) can be outlined. The mother-daughter relationships are shown by arrows pointing from mother to daughter(s), or by inclusion in the mother. The laser rod is segmented so that the energy deposition pattern can be found.

it may be found.) The decomposition proceeds in a straight-forward way from the all-enclosing segment 1 through smaller and smaller segments, always keeping the number of daughters small at each level. In fact, the number of daughters per level may be unnecessarily small - a comparison run with more daughters per mother in the rod gave essentially identical run times. Once the mother-daughter decomposition of the geometry is decided, the preparation of the input is easy (if tedious).

3.5.3 Input Preparation

While reading the following explanation of the input information the reader should refer to the listing of the computer input and output reproduced at the end of this section.

3.5.3.1 Reflection Data

Aside from the built-in reflection types 1, 2 and 3 (dummy boundary, total reflection, and dielectric boundary respectively) we will need three defined reflection types:

1. reflection varying smoothly from .85 for rays normal to the surface to 1.0 at grazing incidence to represent the reflector and other internal metal surfaces;
2. diffuse reflection returning half the incident light, to roughly represent the complicated end and electrode structure in the lamp;
3. reflection varying smoothly from .95 for rays normal to the surface to 1.0 at grazing incidence to model the dielectric mirrors at the ends of the laser rod.

These three types of reflection are entered as reflection types 11, 12 and 13.

3.5.3.2 Material Data

The metal, air and quartz materials are entered in a straightforward manner (the refractive indices for the metals and air are made slightly different so that ZAP will know that the boundaries between them are not just dummy boundaries, as it would assume if their indices were the same - see subroutine BOUNC(). The xenon lamp plasma and Nd^{3+} - doped glass have absorption coefficients which vary with wavelength, and the user-written subroutines ABS2 and ABS3 must be supplied. These routines (see listing at end of section) are self-explanatory.

The absorption coefficient of the metals is made very large so that any light entering them will be immediately absorbed. Note that a small absorption has been added to the glass at all wavelengths; this is to insure some absorption (even if small) for all wavelengths, to avoid rays that dribble on forever.

3.5.3.3 Boundary Data

The boundaries (in this case only spheres, cylinders and planes) are just those necessary to specify the segments previously decided on. Because ZAP currently handles surfaces through the origin, the center of the geometry is displaced by .001 on each axis. When two reflection properties are required for different parts of a boundary, two coinciding boundaries are specified with different reflections, and the choice between them is made when the boundaries of segments are specified (note boundaries 5, 11 and 13).

3.5.3.4 Segment Data

Once the boundaries are specified, the segments are defined by giving all boundaries of each (and the volume, if the energy density is desired for that segment). The process is quite simple.

3.5.3.5 Structure Data

The mother-daughter relationships are entered for each segment. The information is most easily prepared by reference to a decomposition diagram such as Figure 3.8.

3.5.3.6 Lamp Data

For this problem there is only one type of source. This is the volume-emitting xenon plasma in the lamp. Its properties are specified in the user-supplied subroutine INTEN1, which is reproduced at the end of this section.

3.5.3.7 Source Data

There is only one source, namely the xenon lamp. It is specified geometrically by one boundary and a rectangular parallelopiped. For this run 500 rays are called for from the lamp, in order to get acceptably low errors in the segment deposition energies in the rod.

3.5.3.8 Test Data

Test points are specified for all segments in this example, although this is not necessary in general. Option 1 is used except when the segment volume is zero (because daughter segments take up all its volume), in which case Option 0 is used. Segments 1 and 2 also have points specified outside them (negative segment number). All points are correct, so no error messages appear.

3.5.3.9 Plot Data

Five plots are called for. There is a cross section near the center of the sphere (but just above the symmetry boundary) perpendicular to the rod and lamp; detail of the rod and lamp is poor because of the limited printer resolution. Another plot parallel to and through the rod and lamp suffers from the same lack of detail, although the general configuration is clear from both. The third plot is a close-up of the lamp-rod-holders-sphere area of the second plot; it clearly shows the quartz lamp wall, rod segmentation, and holder details. The fourth and fifth plots are close-up views of cuts across the rod and lamp respectively. These plots are very useful in checking that the geometry has been specified just as desired, and that no silly errors have crept in.

3.5.4 Discussion of Output

The output due to test points and plot requests has been discussed above. Here the power deposition results will be discussed.

3.5.4.1 Segment Results

The most interesting information in the segment results is the pattern of power deposition in the laser rod. The half of the rod near the sphere wall (segments 14, 15, 16 and 17) and the half near the center (segments 20. 21, 22 and 23) get essentially the same amount of scaled power - 47.13% and 52.86% respectively (we get these figures by adding the numbers in the percent scaled power column). The lensing effect of the laser rod has concentrated more power in the core of the rod (segments 14, 16, 20 and22) than in the skin (segments 15, 17, 21 and 23); the core got 60.46% and the skin 39.53%. This effect is apparent in both the center and end sections of the rod. Because the 500 rays have been enough to give approximately 10% errors in the deposition powers in the rod segments (see percent error column), these conclusions are reasonably reliable.

3.5.4.2 Material Results

The material results tell us the distribution of power among the various elements of the laser assembly. From the percent total power column, we see that the lamp absorbs by far the greatest fraction of the initial power. However, the lamp is a volume emitter and much of the power created in its volume may be absorbed before it ever gets out. To find out how much is internally reabsorbed in this way, another run was made with the absorption coefficient of the "air" in the cavity equal to 1000 cm^{-1}. The lamp was found to absorb 76.59% (error 2.29%) of the radiation before it got out for the first time, leaving 23.21% (error 7.64%) of the initial power as the amount actually emitted from the lamp (the remaining .2% was absorbed in the lamp ends). Thus we find that the cavity and holders absorbed 9.58% of the initial power (41.28% of the emitted power), the rod absorbed 6.70% (29.30%), and the lamp reabsorbed 7.02% (30.25%). The power returned to the lamp will act much like the lamp electrical input power (because the thermalization time in the dense lamp plasma is very short). If a fraction R of the lamp input is radiated as light with the remaining 1-R lost as heat, and if R is not changed ~~greatly by the self-loading due~~ to returned power (probably a good assumption for the low self-loading here, but more questionable with higher loadings), we can make a rough self-consistent calculation of what happends to the returned power and what the deposition fractions are as follows (assume all spectral regions act like the .4 - .92 μ region we calculated):

The input electrical power is P

The power returned to the lamp from the cavity is Q

The total input is thus P+Q

The lamp light out is R(P+Q)

Then Q = R(P+Q)F or Q = (RFP)/(1-RF) where F is the fraction of lamp output reabsorbed (F is .3025 for the geometry we analyzed).

Then if F^1 is the fraction of P re-absorbed, we have F^1=Q/P = (FR)/(1-RF)

And if L is the power absorbed by the laser rod

And if G is the fraction of lamp output which the rod gets (G is .2390 for our laser)

Then L = GR(P+Q) = (GRP)/(1-RF) and so G^1 = L/P = (GR)/(1-RF). Similarly, if C is the fraction of lamp output the cavity gets then C^1 = (CR)/(1-RF).

Thus we see that self-consistency requires that all deposition fractions be multiplied by the factor R/(1-RF). Taking the reasonable value of .5 for R, we find this factor to be about .59 for geometry we analyzed.

From the material power and scaled power for the laser glass (material 6) we find that 57% of the power the laser glass absorbed was useful laser power (the remainder was converted to heat in the rod when the absorbed photon energy was reduced to upper-laser level energy by radiationless transitions after absorption). The self-consistent fraction of electrical input the rod absorbed is .18, so .10 was useful for laser operation and .08 went to rod heat (we have assumed a quantum efficiency of 1.0, which may be too high).

Our results, modified by the above self-consistency argument, thus imply that:

The electrical input was	1.00
The lamp heat loss was	.58
The cavity wall absorption was	.24
The laser rod heat loss was	.08
The upper-laser-level result was	.10

3.5.4.3 Summary Results

The total absorbed power and total source power are slightly different because of statistical fluctuation in the way rays are killed off. The execution time (on a CDC 3800, which has floating point add-substract, multiply, and divide times of about 2, 5 and 10 μs) was 1855.469 seconds. A run with one ray shows that the setup time is about 30 seconds, and thus the run time was roughly

$$T \cong 30 + 3.7\ N \text{ seconds}$$

where N is the number of rays (each with 200 wavelengths) traced. The program and storage occupied about 60,000 words (48 bits each) of storage.

3.5.5 Conclusions

We have found that about 10% of the input electrical power is converted into a pumping rate into the upper laser level for the laser geometry and lamp conditions we specified. The actual laser output available will be decreased by spontaneous emission and (for pulsed lasers) by the fact that not all the upper-level energy can be extracted. However, the upper-level pump rate is probably the best measure of cavity efficiency and thus the best number to use when comparing cavities.

SAMPLE PROBLEM #2 - USER SUPPLIED SUBROUTINES

```
      SUBROUTINE ABS2 ( XLAM, MAXF, TSIG, M )
C********** THIS SUBROUTINE READS IN THE CURRENT DENSITY AND DIAMETER
C********** OF THE FLASHLAMP, AND THE SCALE FACTOR FOR INPUT DIMENSIONS.
C********** THE SCALE FACTOR SPECIFIES THE NUMBER OF CENTIMETERS IN ONE
C********** UNIT OF THE QUANTITY USED FOR INPUT SIZE SPECIFICATIONS.
C********** THUS IF THE INPUT IS IN INCHES, SCALE = 2.54, AND IF THE
C********** INPUT IS IN CENTIMETERS, SCALE = 1.0.  THE CURRENT DENSITY IS
C********** IN AMPS PER SQUARE INPUT UNIT, AND THE DIAMETER IN INPUT
C********** UNITS.  THEREFORE, THE SCALE OF THE ENTIRE PROBLEM MAY BE
C********** CHANGED MERELY BY CHANGING SCALE.  THIS SUBROUTINE SHOULD BE
C********** ENTERED BEFORE ABS3, BECAUSE ABS3 USES THE INFORMATION READ
C********** BY THIS ROUTINE AND STORED IN COMMON.
      DIMENSION XLAM(1), TSIG(1)
      COMMON /CUR/ CUR, DIAM, SCALE
      READ 20, CUR, DIAM, SCALE
      PRINT 30, CUR, DIAM, SCALE
C********** CONVERT TO MKS UNITS
      CUR = 10000.*CUR/SCALE/SCALE
      DIAM = .01*DIAM*SCALE
C********** FILL UP ABSORBTION COEFF ARRAY
      DO 10 IA=1,MAXF
        TSIG(IA) = ALPHA(XLAM(IA),CUR)*.01*SCALE
   10 CONTINUE
      RETURN
   20 FORMAT(3E20.9)
   30 FORMAT(20X,23HLAMP CURRENT DENSITY = ,E16.9,
     1  30H AMPS PER SQUARE INPUT LENGTH UNIT/
     2  20X,19HASSUMED DIAMETER = ,E16.9,19H INPUT LENGTH UNITS/
     3  20X,15HSCALE FACTOR = ,E16.9,
     4  30H CENTIMETERS PER INPUT LENGTH UNIT)
      END
```

SAMPLE PROBLEM #2 - USER SUPPLIED SUBROUTINES

```
      SUBROUTINE ABS3 ( XLAM, MAXF, TSTG, N )
C*********   THIS SUBROUTINE DETERMINES, FOR EACH OF MAXF WAVELENGTHS
C********* STORED IN XLAM, THE ABSORPTION COEFFICIENT (IN RECIPROCAL
C********* INPUT LENGTH UNITS) OF O-I ED-2 ND3+ LASER GLASS.  THE
C********* INPUT INFORMATION TO THE SUBROUTINE IS A DECK OF 261 CARDS
C********* CONTAINING WAVELENGTHS (IN MICRONS) AND ABSORPTION COEFFI-
C********* CIENTS (IN PER CENTIMETERS) AT 20 ANGSTROM INTERVALS FROM
C********* 4000 TO 9200 ANGSTROMS.  EACH CARD HAS A SEQUENCE NUMBER
C********* IN I3 FORMAT, 5 BLANKS, AND THE WAVELENGTH AND ABSORBTION
C********* COEFFICIENT IN 2E10.6 FORMAT.
C*********   FOR EACH WAVELENGTH IN XLAM, THE SUBROUTINE DETERMINES IF
C********* THAT WAVELENGTH IS WITHIN THE 4000 - 9200 ANGSTROM REGION.
C********* IF IT IS NOT, THE ABSORPTION COEFFICIENT AT THAT WAVELENGTH
C********* IS SET TO A SMALL VALUE.  IF IT IS, THE ABSORPTION COEFFI-
C********* CIENT IS FOUND BY LINEAR INTERPOLATION BETWEEN THE TWO
C********* NEAREST DATA CARD VALUES.
      DIMENSION XLAM(1), TSTG(1), WAVAR(261), ALPHAR(262)
      COMMON /CUR/ CUR, DIAM, SCALE

C********* READ IN DATA CARD DECK
      DO 30 IA=1,261
        READ 80,IB,WAV,ALPH
C********* CHECK FOR CARD OUT OF SEQUENCE
        IF(IA-IB) 10,20,10
   10   PRINT 90,IB
   20   WAVAR(IA) = WAV
        ALPHAR(IA) = (ALPH+.01)*SCALE
   30 CONTINUE
C********* PUT IN EXTRA ELEMENT FOR INTERPOLATION AT LAST POINT
      ALPHAR(262) = .01*SCALE

C********* FILL TSTG WITH ABSORPTION COEFFICIENTS CORRESPONDING TO XLAMS
      DO 70 IC=1,MAXF
        YLAM = XLAM(IC)
C********* TEST IF BELOW MIN WAVELENGTH
        IF(YLAM-.4) 40,40,50
   40   TSTG(IC) = .01*SCALE
        GOTO 70
C********* TEST IF ABOVE MAX WAVELENGTH
   50   IF(YLAM-.92) 60,40,40
C********* IF BETWEEN LIMITS, FIND INDEX OF DATA CARD JUST BELOW
   60   N = (YLAM-.4)*500. + 1.
C********* FIND AB. CO. BY LINEAR INTERPOLATION BETWEEN BRACKETING CARDS
        TSTG(IC)=ALPHAR(N)+(YLAM-WAVAR(N))*500.*(ALPHAR(N+1)-ALPHAR(N))
   70 CONTINUE
      PRINT 100
      RETURN
   80 FORMAT(I3,5X,2E10.6)
   90 FORMAT(*0GLASS ABSORPTION CARD *I3* OUT OF ORDER - CONTINUING*)
  100 FORMAT(20X,29HGLASS DATA READ IN FROM CARDS)
      END
```

SAMPLE PROBLEM #2 - USER SUPPLIED SUBROUTINES

```
      SUBROUTINE INTEMI ( XLAM, MAXF, TSTG, LAMNO )
C********** THIS SUBROUTINE STORES IN TSTG FOR EACH WAVELENGTH IN XLAM
C********** THE LAMP VOLUME EMISSION IN WATTS PER MICRON PER CUBIC INPUT
C********** LENGTH UNIT.  IT IS BASED ON THE FACT THAT THE VOLUME
C********** EMISSION IS 4 TIMES THE BLACK BODY SPECTRAL EMISSIVITY TIMES
C********** THE ABSORPTION-EMISSION COEFFICIENT FOR A PLASMA IN LOCAL
C********** THERMAL EQUILIBRIUM.  THE TEMPERATURE USED FOR THE BLACK BODY
C********** EMISSIVITY IS ASSUMED UNIFORM ACROSS THE LAMP.
      DIMENSION XLAM(1), TSTG(1)
      COMMON /CUR/ CUR, DIAM, SCALE
C********** THE TEMPERATURE OF THE LAMP IS FOUND FROM AN EMPIRICAL FORMUL
      TLO = 4450.*DIAM**.03*CUR**.01
      THI = 43.*DIAM**.27*CUR**.34
      T = (TLO**6+THI**6)**.1666667
C********** THE SPECIFIC OUTPUT IS THE BLACK BODY EMITTANCE TIMES THE
C********** ABSORBTION COEFFICIENT TIMES FOUR.
      DO 10 IA=1,MAXF
        X = XLAM(IA)
        DENOM = EXP(AMIN1(14387.9/X/T,69.)) - 1.
        BLACK = 3.7405E8/X/X/X/X/X/DENOM
        TSTG(IA) = 4.*ALPHA(X,CUR)*BLACK*SCALE*SCALE*SCALE*1.E-6
   10 CONTINUE
      RETURN
      END
```

SAMPLE PROBLEM #2 - USER SUPPLIED SUBROUTINES

```
      FUNCTION ALPHA ( WAV, CUR )
C********** THIS FUNCTION RETURNS THE APPROXIMATE ABSORPTION-EMISSION
C********** COEFFICIENT AT WAVELENGTH WAV (MICRONS) OF A XENON PLASMA
C********** WITH CURRENT DENSITY CUR (AMPS PER SQUARE METER) FLOWING THRU
C********** IT.  THE APPROXIMATION CONSISTS OF A SET OF LORENTZIAN LINES
C********** OF FIXED POSITION AND WIDTH PLUS A CONTINUUM, ALL OF WHICH
C********** ARE PROPORTIONAL TO THE SQUARE OF THE CURRENT DENSITY.
C********** THE RETURNED VALUE IS IN RECIPROCAL METERS.
C********** MODEL BY JOHN B. TRENHOLME AS OF 27 MARCH 1970
C**********
C********** THE FOLLOWING DATA BLOCK CONTAINS THE XENON LINE SPECTRUM
C********** USED TO FIND THE ABSORPTION-EMISSION COEFFICIENT.  EACH GROUP
C********** OF THREE NUMBERS REPRESENTS THE CENTER WAVELENGTH (MICRONS),
C********** PEAK ABSORPTION-EMISSION (PER METER), AND FULL WIDTH AT HALF
C********** MAXIMUM (MICRONS) FOR ONE LORENTZIAN LINE AT 1000 AMPS PER
C********** SQUARE CENTIMETER (1.E7 AMPS PER SQUARE METER).
      DIMENSION XE(81)
      DATA (NXE=81), (XE= .4560,1.,.015, .4920,1.,.015, .6077,2.,.015,
     1 .7643,4.,.015, .8232,375.,.008, .8280,300.,.003,
     2 .8347,225.,.004, .8409,225.,.003, .8819,375.,.009,
     3 .8952,300.,.004, .9045,375.,.003, .9162,375.,.006,
     4 .9374,150.,.007, .9513,150.,.007, .9800,375.,.004,
     5 .9923,375.,.004, 1.0107,120.,.007, 1.0865,30.,.007,
     6 1.1100,45.,.007, 1.1742,75.,.007, 1.2623,45.,.007,
     7 1.3656,30.,.007, 1.4180,30.,.015, 1.4732,75.,.007,
     8 1.5418,30.,.007, 1.6052,15.,.007, 1.6728,10.,.007)
C********** FIRST THE APPROXIMATE CONTINUUM IS EVALUATED AT 1000 A/CM2
      AL = 15.*EXP(-8.*(WAV-.7)*(WAV-.7)) + 1.
C********** THEN THE LINES ARE ADDED
      DO 10 J=1,NXE,3
        AL = AL + XE(J+1)/(4.*((WAV-XE(J))/XE(J+2))*((WAV-XE(J))/XE(J+2)
     1    ) + 1.)
   10 CONTINUE
C********** THE RESULT IS SCALED BY THE SQUARE OF THE CURRENT DENSITY
      RATIO = CUR/1.E7
      ALPHA = AL*RATIO*RATIO
      RETURN
      END
```

SAMPLE PROBLEM #2 - TEST RUN INPUT

```
MULTIFREQUENCY TEST ON SPHERE WITH ROD AND LAMP
.5              0.0           .4           .92
  200       0       0                  1
  11 FUNCT  .15
  12 DIFFUS .5
  13 FUNCT  .05

  1          1000.   .99    0.    METAL SPHERICAL REFLECTOR
  2          1000.   .98    0.    METAL CYLINDRICAL HOLDERS
  3          0.      1.     0.    AIR INSIDE SYSTEM
  4          .001    1.46   0.    QUARTZ LAMP ENVELOPE
  5 ABS2     0.      1.01   0.    XENON PLASMA IN LAMP
  3000.              1.                       1.
  6 ABS3     0.      1.56   1.06  0-1 EU-2 ND3+ LASER GLASS IN ROD
 1                4.000000-001       0.000000+000
 2                4.020000-001       2.150400-001
 3                4.040000-001       2.073600-001
 4                4.060000-001       1.920000-001
 5                4.080000-001       1.689600-001
 6                4.100000-001       1.536000-001
 7                4.120000-001       1.766400-001
 8                4.140000-001       1.766400-001
 9                4.160000-001       1.574400-001
10                4.180000-001       1.536000-001
11                4.200000-001       1.612800-001
12                4.220000-001       1.766400-001
13                4.240000-001       1.689600-001
14                4.260000-001       1.612800-001
15                4.280000-001       1.920000-001
16                4.300000-001       3.456000-001
17                4.320000-001       4.992000-001
18                4.340000-001       3.072000-001
19                4.360000-001       1.920000-001
20                4.380000-001       1.459200-001
21                4.400000-001       1.305600-001
22                4.420000-001       1.152000-001
23                4.440000-001       1.152000-001
24                4.460000-001       9.216000-002
25                4.480000-001       1.382400-001
26                4.500000-001       1.459200-001
27                4.520000-001       1.689600-001
28                4.540000-001       2.073600-001
29                4.560000-001       2.841600-001
30                4.580000-001       2.995200-001
31                4.600000-001       3.072000-001
32                4.620000-001       3.225600-001
33                4.640000-001       3.072000-001
34                4.660000-001       3.456000-001
35                4.680000-001       3.840000-001
36                4.700000-001       4.147200-001
37                4.720000-001       4.838400-001
38                4.740000-001       4.454400-001
39                4.760000-001       4.454400-001
40                4.780000-001       4.377600-001
41                4.800000-001       3.840000-001
42                4.820000-001       3.072000-001
43                4.840000-001       1.996800-001
44                4.860000-001       1.536000-001
45                4.880000-001       1.382400-001
46                4.900000-001       1.228800-001
47                4.920000-001       1.305600-001
```

SAMPLE PROBLEM #2 - TEST RUN INPUT

```
 48          4.940000-001          1.459200-001
 49          4.960000-001          2.073600-001
 50          4.980000-001          2.688000-001
 51          5.000000-001          2.688000-001
 52          5.020000-001          3.072000-001
 53          5.040000-001          3.840000-001
 54          5.060000-001          4.992000-001
 55          5.080000-001          5.990400-001
 56          5.100000-001          7.987200-001
 57          5.120000-001          1.036800+000
 58          5.140000-001          1.213440+000
 59          5.160000-001          1.036800+000
 60          5.180000-001          9.600000-001
 61          5.200000-001          9.600000-001
 62          5.220000-001          1.013760+000
 63          5.240000-001          1.336320+000
 64          5.260000-001          1.950400+000
 65          5.280000-001          1.950720+000
 66          5.300000-001          1.689600+000
 67          5.320000-001          1.420800+000
 68          5.340000-001          1.036800+000
 69          5.360000-001          6.912000-001
 70          5.380000-001          4.224000-001
 71          5.400000-001          2.611200-001
 72          5.420000-001          1.920000-001
 73          5.440000-001          9.216000-002
 74          5.460000-001          4.608000-002
 75          5.480000-001          4.608000-002
 76          5.500000-001          5.376000-002
 77          5.520000-001          4.608000-002
 78          5.540000-001          6.144000-002
 79          5.560000-001          7.680000-002
 80          5.580000-001          9.984000-002
 81          5.600000-001          1.152000-001
 82          5.620000-001          1.305600-001
 83          5.640000-001          2.688000-001
 84          5.660000-001          6.144000-001
 85          5.680000-001          1.1[illegible]+000
 86          5.700000-001          1.884000+000
 87          5.720000-001          3.187200+000
 88          5.740000-001          4.108800+000
 89          5.760000-001          4.492800+000
 90          5.780000-001          4.646400+000
 91          5.800000-001          4.646400+000
 92          5.820000-001          5.414400+000
 93          5.840000-001          6.566400+000
 94          5.860000-001          7.180800+000
 95          5.880000-001          6.720000+000
 96          5.900000-001          5.299200+000
 97          5.920000-001          4.224000+000
 98          5.940000-001          3.302400+000
 99          5.960000-001          2.611200+000
100          5.980000-001          1.920000+000
101          6.000000-001          1.420800+000
102          6.020000-001          1.075200+000
103          6.040000-001          7.680000-001
104          6.060000-001          5.376000-001
105          6.080000-001          3.840000-001
106          6.100000-001          2.688000-001
107          6.120000-001          2.227200-001
108          6.140000-001          1.459200-001
109          6.160000-001          1.228800-001
110          6.180000-001          1.228800-001
111          6.200000-001          1.382400-001
112          6.220000-001          1.536000-001
113          6.240000-001          1.536000-001
114          6.260000-001          1.536000-001
115          6.280000-001          1.536000-001
116          6.300000-001          1.382400-001
117          6.320000-001          1.305600-001
118          6.340000-001          1.228800-001
119          6.360000-001          1.075200-001
```

SAMPLE PROBLEM #2 - TEST RUN INPUT

```
120          6.380000-001       9.216000-002
121          6.400000-001       8.448000-002
122          6.420000-001       7.680000-002
123          6.440000-001       7.680000-002
124          6.460000-001       7.680000-002
125          6.480000-001       6.912000-002
126          6.500000-001       6.912000-002
127          6.520000-001       6.912000-002
128          6.540000-001       6.912000-002
129          6.560000-001       6.912000-002
130          6.580000-001       7.680000-002
131          6.600000-001       7.680000-002
132          6.620000-001       7.680000-002
133          6.640000-001       7.680000-002
134          6.660000-001       7.680000-002
135          6.680000-001       9.216000-002
136          6.700000-001       1.228800-001
137          6.720000-001       1.459200-001
138          6.740000-001       1.536000-001
139          6.760000-001       2.073600-001
140          6.780000-001       2.304000-001
141          6.800000-001       2.611200-001
142          6.820000-001       2.995200-001
143          6.840000-001       3.456000-001
144          6.860000-001       3.225600-001
145          6.880000-001       2.841600-001
146          6.900000-001       2.304000-001
147          6.920000-001       1.536000-001
148          6.940000-001       1.152000-001
149          6.950000-001       6.912000-002
150          6.980000-001       6.912000-002
151          7.000000-001       3.840000-002
152          7.020000-001       4.608000-002
153          7.040000-001       4.608000-002
154          7.060000-001       4.608000-002
155          7.080000-001       4.608000-002
156          7.100000-001       4.608000-002
157          7.120000-001       4.608000-002
158          7.140000-001       5.376000-002
159          7.160000-001       6.144000-002
160          7.180000-001       6.144000-002
161          7.200000-001       7.680000-002
162          7.220000-001       9.216000-002
163          7.240000-001       1.305600-001
164          7.260000-001       1.920000-001
165          7.280000-001       2.841600-001
166          7.300000-001       3.840000-001
167          7.320000-001       6.912000-001
168          7.340000-001       1.382400+000
169          7.360000-001       2.304000+000
170          7.380000-001       3.609600+000
171          7.400000-001       3.632640+000
172          7.420000-001       3.763200+000
173          7.440000-001       3.609600+000
174          7.460000-001       3.648000+000
175          7.480000-001       4.070400+000
```

SAMPLE PROBLEM #2 - TEST RUN INPUT

```
 176          7.500000-001     4.147200+000
 177          7.520000-001     3.456000+000
 178          7.540000-001     2.995200+000
 179          7.560000-001     2.534400+000
 180          7.580000-001     1.843200+000
 181          7.600000-001     1.344000+000
 182          7.620000-001     1.075200+000
 183          7.640000-001     7.680000-001
 184          7.660000-001     6.144000-001
 185          7.680000-001     4.608000-001
 186          7.700000-001     3.686400-001
 187          7.720000-001     3.072000-001
 188          7.740000-001     3.072000-001
 189          7.760000-001     3.072000-001
 190          7.780000-001     3.225600-001
 191          7.800000-001     3.840000-001
 192          7.820000-001     4.608000-001
 193          7.840000-001     6.144000-001
 194          7.860000-001     7.680000-001
 195          7.880000-001     1.036800+000
 196          7.900000-001     1.305600+000
 197          7.920000-001     1.706400+000
 198          7.940000-001     2.304000+000
 199          7.960000-001     2.995200+000
 200          7.980000-001     3.456000+000
 201          8.000000-001     3.801600+000
 202          8.020000-001     3.916800+000
 203          8.040000-001     4.303500+000
 204          8.060000-001     6.259200+000
 205          8.080000-001     6.182400+000
 206          8.100000-001     4.761600+000
 207          8.120000-001     3.417600+000
 208          8.140000-001     2.688000+000
 209          8.160000-001     1.996800+000
 210          8.180000-001     1.536000+000
 211          8.200000-001     1.228800+000
 212          8.220000-001     1.075200+000
 213          8.240000-001     8.83[illegible]00-001
 214          8.260000-001     7.296000-001
 215          8.280000-001     5.376000-001
 216          8.300000-001     4.224000-001
 217          8.320000-001     3.456000-001
 218          8.340000-001     2.457600-001
 219          8.360000-001     1.766400-001
 220          8.380000-001     1.382400-001
 221          8.400000-001     1.382400-001
 222          8.420000-001     1.382400-001
 223          8.440000-001     1.382400-001
 224          8.460000-001     1.382400-001
 225          8.480000-001     1.382400-001
 226          8.500000-001     1.459200-001
 227          8.520000-001     1.536000-001
 228          8.540000-001     1.689600-001
 229          8.560000-001     2.150400-001
 230          8.580000-001     3.225600-001
 231          8.600000-001     4.224000-001
 232          8.620000-001     5.990400-001
 233          8.640000-001     7.449600-001
 234          8.660000-001     9.216000-001
 235          8.680000-001     9.600000-001
 236          8.700000-001     9.600000-001
 237          8.720000-001     9.676800-001
 238          8.740000-001     1.036800+000
 239          8.760000-001     1.305600+000
```

SAMPLE PROBLEM #2 - TEST RUN INPUT

```
 240           8.780000-001      1.035940+000
 241           8.800000-001      1.536000+000
 242           8.820000-001      1.344000+000
 243           8.840000-001      1.113600+000
 244           8.860000-001      8.832000-001
 245           8.880000-001      7.296000-001
 246           8.900000-001      6.758400-001
 247           8.920000-001      5.760000-001
 248           8.940000-001      4.838400-001
 249           8.960000-001      3.840000-001
 250           8.980000-001      3.456000-001
 251           9.000000-001      2.918400-001
 252           9.020000-001      2.600000-001
 253           9.040000-001      2.150400-001
 254           9.060000-001      1.536000-001
 255           9.080000-001      1.152000-001
 256           9.100000-001      7.680000-002
 257           9.120000-001      6.144000-002
 258           9.140000-001      4.608000-002
 259           9.160000-001      3.072000-002
 260           9.180000-001      1.536000-002
 261           9.200000-001      0.000000+000
   1   2 SPHERE .001   .001   .001   100.
   2  11 SPHERE .001   .001   .001   5.5
   3   2 PLANE         1.            .001   .001   .001
   4   2 PLANE                1.     .001   .001   .001
   5   1 PLANE                1.     .001   .001   5.
   6  11 CYLIND               1.     1.     .001   5.     .55
   7  11 CYLIND               1.     -1.    .001   5.     .05
   8   3 CYLIND               1.     1.     .001   .001   .5
   9   3 CYLIND               1.     -1.    .001   .001   .6
  10   3 CYLIND               1.     -1.    .001   .001   .5
  11  12 PLANE                1.     .001   .001   5.
  12   1 PLANE                1.     .001   .001   2.5
  13  13 PLANE                1.     .001   .001   5.
  14   1 PLANE   1.                  1.     .001   .001
  15   1 CYLIND               1.     1.     .001   .001   .354
   1   1    1    0    0    0    0    0    0    0    0    0
   2   3    2   -3   -4    0    0    0    0    0    0    0    0 0.
   3   3    2   -3   -5    0    0    0    0    0    0    0    0 0.
   4   3    2   -3   -4    5    0    0    0    0    0    0    0 0.
   5   2    2   -3   -5    6    0    0    0    0    0    0    0 0.
   6   2    2   -3   -5    7    0    0    0    0    0    0    0 0.
   7   6   -3   -4    5    8    0    0    0    0    0    0    0 0.
   8   4   -3   -4    5    9    0    0    0    0    0    0    0 0.
   9   5   -3   -4   10   11    0    0    0    0    0    0    0 0.
  10   6   -3    5    8  -12    0    0    0    0    0    0    0 0.
  11   6   -3   -4    8   12    0    0    0    0    0    0    0 0.
  12   6   -3    5    8  -12  -14    0    0    0    0    0    0 0.
  13   6   -3    5    8  -12   14    0    0    0    0    0    0 0.
  14   6   -3  -12   13   14   15    0    0    0    0    0    0 .246
  15   6   -3    8  -12   13   14  -15    0    0    0    0    0 .245
  16   6   -3  -12   13  -14   15    0    0    0    0    0    0 .246
  17   6   -3    8  -12   13  -14  -15    0    0    0    0    0 .245
  18   6   -3   -4    8   12  -14    0    0    0    0    0    0 0.
  19   6   -3   -4    8   12   14    0    0    0    0    0    0 0.
  20   6   -3   -4   12   14   15    0    0    0    0    0    0 .246
  21   6   -3   -4    8   12   14  -15    0    0    0    0    0 .245
  22   6   -3   -4   12  -14   15    0    0    0    0    0    0 .246
  23   6   -3   -4    8   12  -14  -15    0    0    0    0    0 .245
   1   2
```

SAMPLE PROBLEM #2 - TEST RUN INPUT

```
        2   3   4
        3   5   6
        4   7   0
        7  10  11
        0   9
       10  12  13
       11  18  19
       12  16  17
       13  14  15
       18  22  23
       19  20  21

        1 VOLUME INTEN1

        1   9   1  500 -1.5    -.5      .001    .5      .001    5.

          1     1 10.          10.          10.
         -1     1 60.          60.          60.
          2     0 2.           3.           3.
         -2     0 2.           -3.          3.
          3     1 .3           1.           5.3
          4     1 2.           1.           3.
          5     1 1.1          .3           5.2
          6     1 -.9          .2           5.3
          7     0 1.2          .1           2.4
          8     1 -1.4         .4           4.
          9     1 -.6          .2           .1
         10     0 .9           .4           3.
         11     0 1.3          .3           2.
         12     0 1.1          .4           4.
         13     0 .9           .1           3.
         14     1 .8           .2           4.
         15     1 .7           .3           3.
         16     1 1.2          .2           4.
         17     1 1.3          .3           3.
         18     0 1.2          .2           2.
         19     0 .8           .4           1.
         20     1 .7           .1           2.
         21     1 .6           .2           1.
         22     1 1.3          .1           2.
         23     1 1.4          .2           1.
-6.      -.5      .01      6.       -.5      .01      -6.      6.       .01
-6.      .01      -.5      6.       .01      -.5      -6.      .01      6.
-1.7     .01      4.       1.6      .01      4.       -1.7     .01      6.
.45      -.05     .01      1.55     -.65     .01      .45      .55      .01
-1.65    -.1      .01      -.35     -.1      .01      -1.65    .65      .01
```

SAMPLE PROBLEM #2 - TEST RUN OUTPUT

```
GENERAL INPUT FOR ZAP


MULTIFREQUENCY TEST ON SPHERE WITH ROD AND LAMP


ROULETTE FRACTION=  5.0000-001
DISTANCE BETWEEN CONTINUITIVE BOUNDARIES=  0.0030+000
MINIMUM WAVELENGTH=  4.0000-001
MAXIMUM WAVELENGTH=  9.2000-001
NUMBER OF WAVELENGTHS=   200
RAY PRINT OPTION=      0
DEBUG PRINT OPTION=     0
STARTING RANDOM INTEGER=
                                  1
```

SAMPLE PROBLEM #2 - TEST RUN OUTPUT

```
REFLECTION     TYPE                                   REFLECTION DATA
  NUMBER

    11        FUNCT    0.1500  -0.0000  -0.0000  -0.0000  -0.0000  -0.0000  -0.0000  -0.0000  -0.0000  -0.0000
    12        DIFFUS   0.5000  -0.0000  -0.0000  -0.0000  -0.0000  -0.0000  -0.0000  -0.0000  -0.0000  -0.0000
    13        FUNCT    0.0500  -0.0000  -0.0000  -0.0000  -0.0000  -0.0000  -0.0000  -0.0000  -0.0000  -0.0000



                                                       MATERIAL DATA
MATERIAL   INPUT       ABSORPTION       REFRACTIVE          LASING      DESCRIPTION
 NUMBER   ROUTINE      COEFFICIENT           INDEX      WAVELENGTH
    1                 1000.000000         0.990000        0.000000      METAL SPHERICAL REFLECTOR
    2                 1000.000000         0.980000        0.000000      METAL CYLINDRICAL HOLDERS
    3                    0.000000         1.000000        0.000000      AIR INSIDE SYSTEM
    4                    0.001000         1.460000        0.000000      QUARTZ LAMP ENVELOPE
    5       ABS2         0.000000         1.010000        0.000000      XENON PLASMA IN LAMP
                  LAMP CURRENT DENSITY =  3.000000000+003 AMPS PER SQUARE INPUT LENGTH UNIT
                  ASSUMED DIAMETER =  1.000000000+000 INPUT LENGTH UNITS
                  SCALE FACTOR =  1.000000000+000 CENTIMETERS PER INPUT LENGTH UNIT
    6       ABS3         0.000000         1.560000        1.060000      O-I ED-2 ND. LASER GLASS IN ROD
                  GLASS DATA READ IN FROM CARDS
```

SAMPLE PROBLEM #2 - TEST RUN OUTPUT

```
                                                         BOUNDARY DATA
BOUND  REFL   BOUND   ALPHA    BETA    GAMMA        X        Y        Z    X2   Y2   X3   Y3      DIS   ECC
 NUMB  NUMB    TYPE

   1     2   SPHERE                             0.001    0.001    0.001                      100.000
   2    11   SPHERE                             0.001    0.001    0.001                        5.500
   3     2    PLANE   0.000    1.000    0.000   0.001    0.001    0.001                        0.001
   4     2    PLANE   0.000    0.000    1.000   0.001    0.001    0.001                        0.001
   5     1    PLANE   0.000    0.000    1.000   0.001    0.001    5.000                        5.000
   6    11   CYLIND   0.000    0.000    1.000   1.000    0.001    5.000                        0.550
   7    11   CYLIND   0.000    0.000    1.000  -1.000    0.001    5.000                        0.650
   8     3   CYLIND   0.000    0.000    1.000   1.000    0.001    0.001                        0.500
   9     3   CYLIND   0.000    0.000    1.000  -1.000    0.001    0.001                        0.400
  10     3   CYLIND   0.000    0.000    1.000  -1.000    0.001    0.001                        0.500
  11    12    PLANE   0.000    0.000    1.000   0.001    0.001    5.000                        5.000
  12     1    PLANE   0.000    0.000    1.000   0.001    0.001    2.500                        2.500
  13    13    PLANE   0.000    0.000    1.000   0.001    0.001    5.000                        5.000
  14     1    PLANE   1.000    0.000    0.000   1.000    0.001    0.001                        1.000
  15     1   CYLIND   0.000    0.000    1.000   1.000    0.001    0.001                        0.354


                                                    SEGMENT DATA
SEGMENT  MATERIAL          CONFINING BOUNDARIES
 NUMBER    NUMBER                                                                                 VOLUME

     1         1      1     0     0     0     0     0     0     0     0     0     0     0.000000
     2         3      2    -3    -4     0     0     0     0     0     0     0     0     0.000000
     3         3      2    -3    -5     0     0     0     0     0     0     0     0     0.000000
     4         3      2    -3    -4     5     0     0     0     0     0     0     0     0.000000
     5         2      2    -3    -5     6     0     0     0     0     0     0     0     0.000000
     6         2      2    -3    -5     7     0     0     0     0     0     0     0     0.000000
     7         6     -3    -4     8     8     0     0     0     0     0     0     0     0.000000
     8         4     -3    -4     5     9     0     0     0     0     0     0     0     0.000000
     9         5     -3    -4    10    11     0     0     0     0     0     0     0     0.000000
    10         6     -3     5     8   -12     0     0     0     0     0     0     0     0.000000
    11         6     -3    -4     8    12     0     0     0     0     0     0     0     0.000000
    12         6     -3     5     8   -12   -14     0     0     0     0     0     0     0.000000
    13         6     -3     8     8   -12    14     0     0     0     0     0     0     0.000000
    14         6     -3   -12    13    14    15     0     0     0     0     0     0     0.246000
    15         6     -3     8   -12    13    14   -15     0     0     0     0     0     0.245000
    16         6     -3   -12    13   -14    15     0     0     0     0     0     0     0.246000
    17         6     -3     8   -12    13   -14   -15     0     0     0     0     0     0.245000
    18         6     -3    -4     8    12   -14     0     0     0     0     0     0     0.000000
    19         6     -3    -4     8    12    14     0     0     0     0     0     0     0.000000
    20         6     -3    -4    12    14    15     0     0     0     0     0     0     0.246000
    21         4     -3    -4     8    12    14   -15     0     0     0     0     0     0.245000
    22         6     -3    -4    12   -14    15     0     0     0     0     0     0     0.246000
    23         6     -3    -4     8    12   -14   -15     0     0     0     0     0     0.245000
```

SAMPLE PROBLEM #2 - TEST RUN OUTPUT

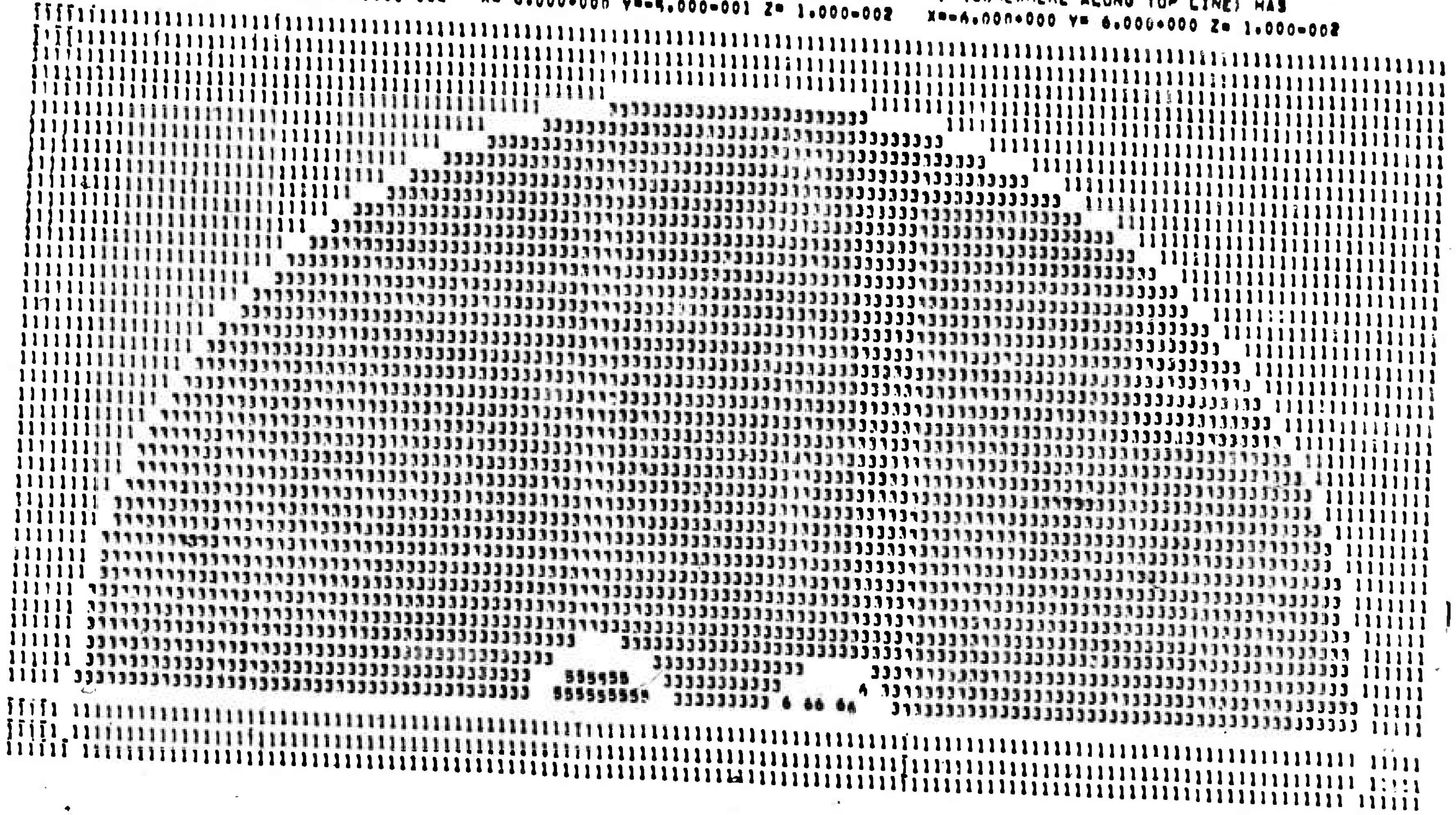
```
                                                STRUCTURE DATA
   MOTHER         DAUGHTER SEGMENTS
   SEGMENT

        1          2
        2          3      4
        3          5      6
        4          7      8
        7         10     11
        8          9
       10         12     13
       11         18     19
       12         16     17
       13         14     15
       18         22     23
       19         20     21



                                                LAMP DATA
    LAMP         LAMP   INTENSITY      ANGLE   INTENSITY
   NUMBER        TYPE     ROUTINE    ROUTINE

        1      VOLUME      INTEN1              =0.0000+000
```

SAMPLE PROBLEM #2 - TEST RUN OUTPUT

```
                                                     SOURCE DATA
   SOURCE   SEGMENT  BOUNDARY      LAMP    NUMBER   GEOMETRIC SOURCE DATA
   NUMBER    NUMBER    NUMBER    NUMBER   OF RAYS

      1         9         0         1       500   -1.50000   -0.50000    0.00100    0.40000    0.00100    5.00000




                                                                   TEST DATA
                     SEGMENT  OPTION           X              Y              Z

                           1       1   1.0000+001     1.0000+001     1.0000+001
                          -1       1   4.0000+001     6.0000+001     6.0000+001
                           2       0   2.0000+000     3.0000+000     3.0000+000
                          -2       0   2.0000+000    -3.0000+000     3.0000+000
                           3       1   3.0000-001     1.0000+000     5.3000+000
                           4       1   2.0000+000     1.0000+000     3.0000+000
                           5       1   1.1000+000     3.0000-001     5.2000+000
                           6       1  -9.0000-001     2.0000-001     5.3000+000
                           7       0   1.2000+000     1.0000-001     2.4000+000
                           8       1  -1.4000+000     4.0000-001     4.0000+000
                           9       1  -6.0000-001     2.0000-001     1.0000-001
                          10       0   9.0000-001     4.0000-001     3.0000+000
                          11       0   1.3000+000     3.0000-001     2.0000+000
                          12       0   1.1000+000     4.0000-001     4.0000+000
                          13       0   9.0000-001     1.0000-001     3.0000+000
                          14       1   8.0000-001     2.0000-001     4.0000+000
                          15       1   7.0000-001     3.0000-001     3.0000+000
                          16       1   1.2000+000     2.0000-001     4.0000+000
                          17       1   1.3000+000     3.0000-001     3.0000+000
                          18       0   1.7000+000     2.0000-001     2.0000+000
                          19       0   8.0000-001     4.0000-001     1.0000+000
                          20       1   7.0000-001     1.0000-001     2.0000+000
                          21       1   6.0000-001     2.0000-001     1.0000+000
                          22       1   1.3000+000     1.0000-001     2.0000+000
                          23       1   1.4000+000     2.0000-001     1.0000+000
```

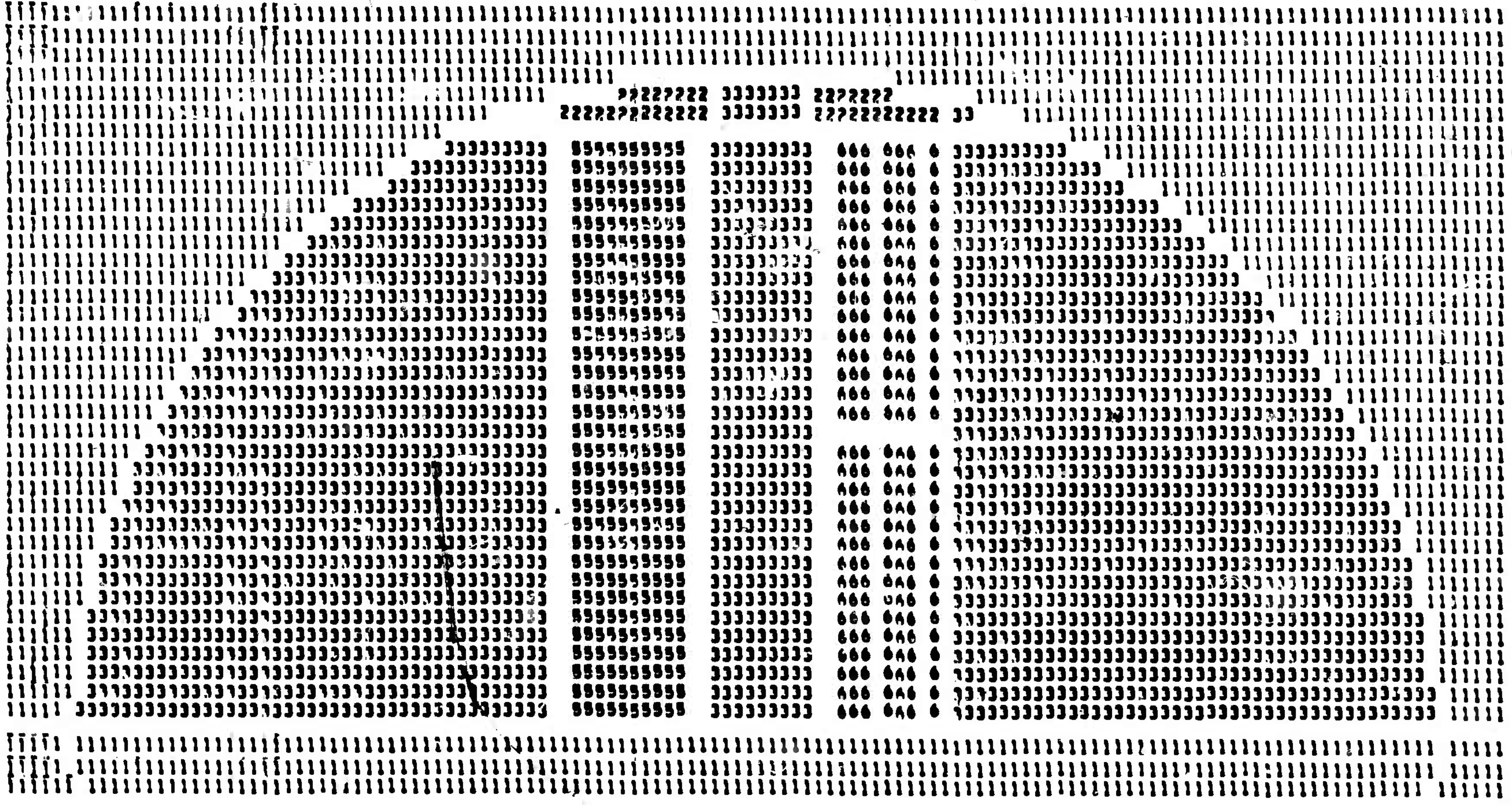
SAMPLE PROBLEM #2 - TEST RUN OUTPUT

```
                                   PLOT OF PLANE DEFINED BY POINTS P0 P1 P2
P0 (LOWER LEFT CORNER OF PLOT) HAS
X=-6.000+000 Y=-5.000-001 Z= 1.000-002   P1 (LOWER RIGHT CORNER OF PLOT) HAS
                                         X= 6.000+000 Y=-5.000-001 Z= 1.000-002   P2 (SOMEWHERE ALONG TOP LINE) HAS
                                                                                  X=-6.000+000 Y= 6.000+000 Z= 1.000-002
```



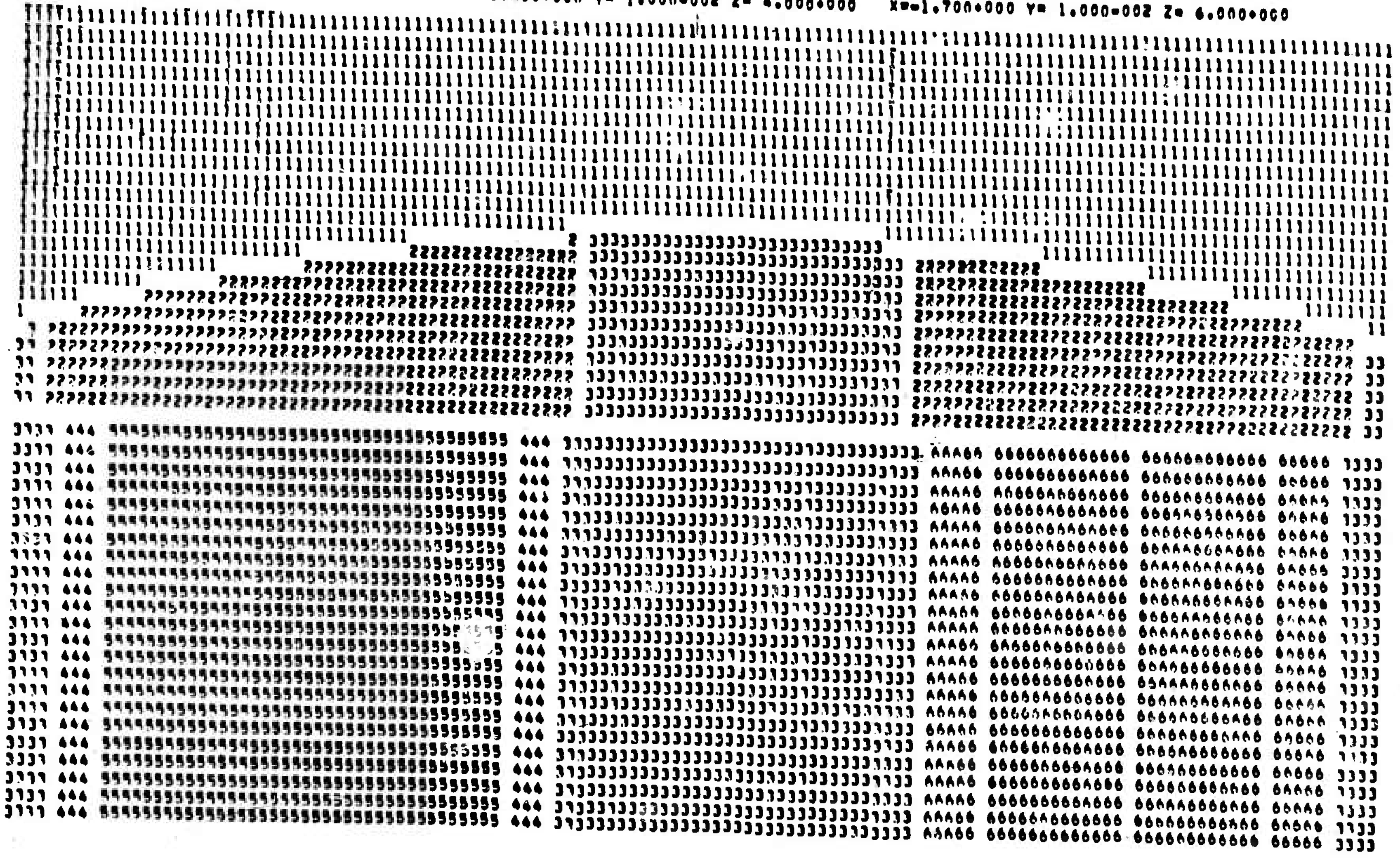
SAMPLE PROBLEM #2 - TEST RUN OUTPUT

```
                              PLOT OF PLANE DEFINED BY POINTS P0 P1 P2

P0 (LOWER LEFT CORNER OF PLOT) HAS       P1 (LOWER RIGHT CORNER OF PLOT) HAS       P2 (SOMEWHERE ALONG TOP LINE) HAS
X=-6.000+000 Y= 1.000-002 Z=-5.000-001   X= 6.000+000 Y= 1.000-002 Z=-5.000-001   X=-6.000+000 Y= 1.000-002 Z= 6.000+000
```



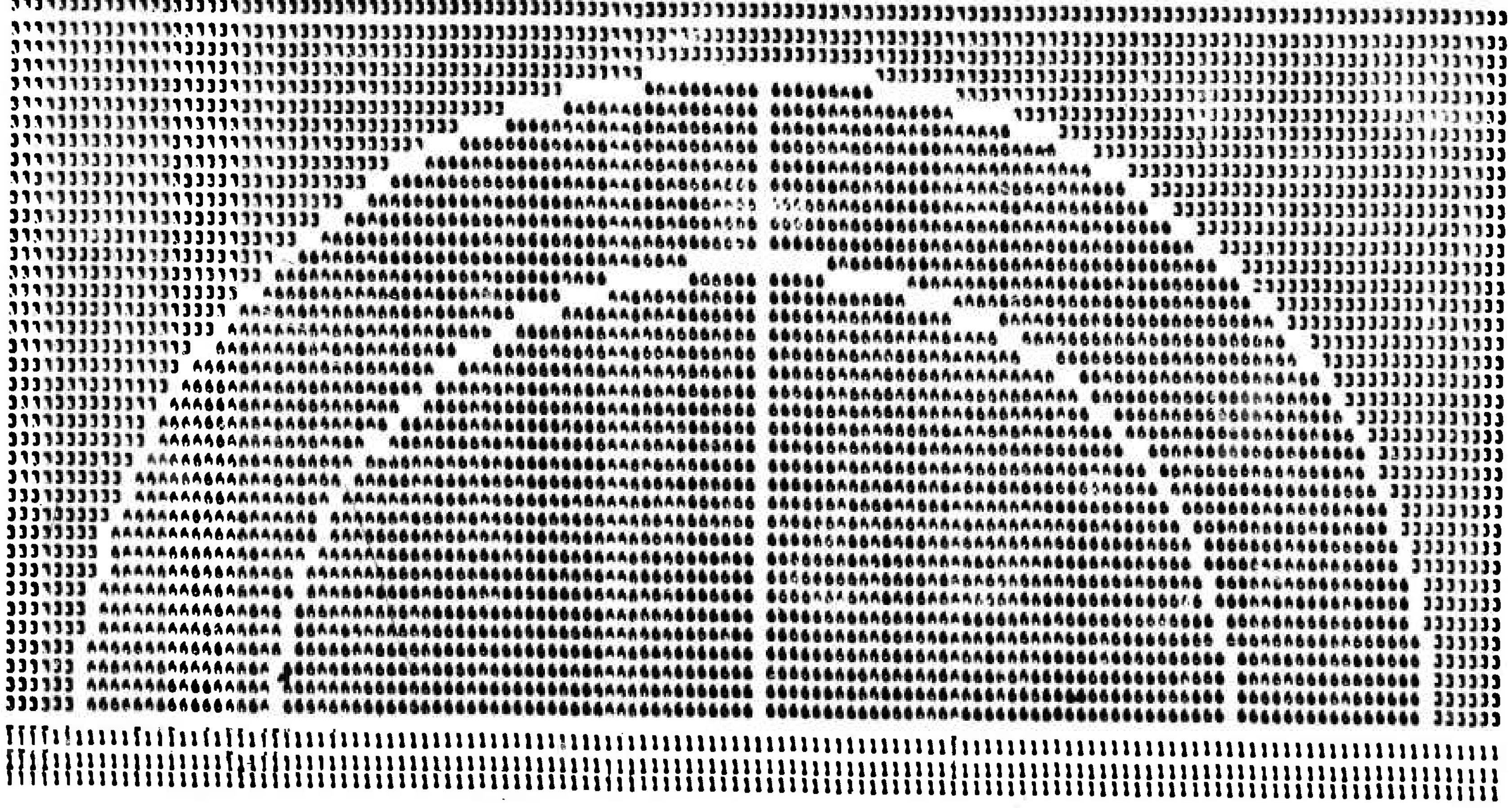
SAMPLE PROBLEM #2 - TEST RUN OUTPUT

```
                                        PLOT OF PLANE DEFINED BY POINTS P0 P1 P2
P0 (LOWER LEFT CORNER OF PLOT) HAS          P1 (LOWER RIGHT CORNER OF PLOT) HAS          P2 (SOMEWHERE ALONG TOP LINE) HAS
X=-1.700+000 Y= 1.000-002 Z= 4.000+000      X= 1.600+000 Y= 1.000-002 Z= 4.000+000       X=-1.700+000 Y= 1.000-002 Z= 6.000+000
```



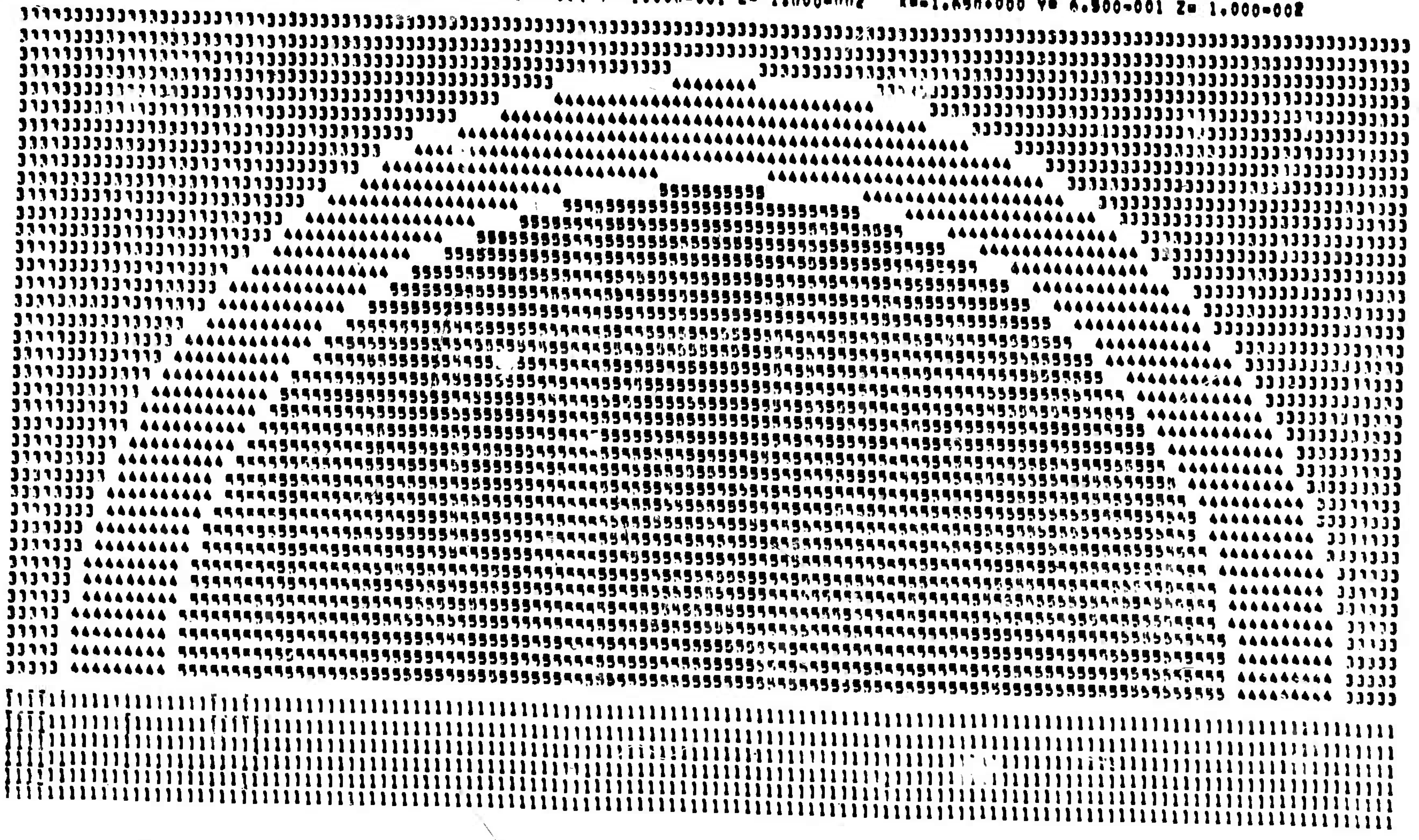
SAMPLE PROBLEM #2 - TEST RUN OUTPUT

```
                                         PLOT OF PLANE DEFINED BY POINTS P0 P1 P2
P0 (LOWER LEFT CORNER OF PLOT) HAS         P1 (LOWER RIGHT CORNER OF PLOT) HAS        P2 (SOMEWHERE ALONG TOP LINE) HAS
X= 4.500-001 Y=-5.000-002 Z= 1.000-002     X= 1.550+000 Y=-5.000-002 Z= 1.000-002    X= 4.500-001 Y= 5.500-001 Z= 1.000-002
```



SAMPLE PROBLEM #2 - TEST RUN OUTPUT

```
                                        PLOT OF PLANE DEFINED BY POINTS P0 P1 P2
P0 (LOWER LEFT CORNER OF PLOT) HAS        P1 (LOWER RIGHT CORNER OF PLOT) HAS        P2 (SOMEWHERE ALONG TOP LINE) HAS
X=-1.650+000 Y=-1.000-001 Z= 1.000-002    X=-3.500-001 Y=-1.000-001 Z= 1.000-002    X=-1.650+000 Y= 6.500-001 Z= 1.000-002
```



SAMPLE PROBLEM #2 - TEST RUN OUTPUT

```
                                                  SEGMENT RESULTS

MOTHER   DAUGHTER MATERIAL TOTAL     SCALED    TOTAL     SCALED     SEGMENT    PERCENT PERCENT   PERCENT TOTAL    TOTAL
SEGMENT  SEGMENT  TYPE     SEGMENT   SEGMENT   POWER     POWER      VOLUME     TOTAL   ERROR IN  SCALED  RAY LEGS RAYS
NUMBER   NUMBER   NUMBER   POWER     POWER     DENSITY   DENSITY    USED       POWER   TOTAL PCT POWER   IN SEG.  IN SEG.
   1
            1        1     4.55+009 0.00+000 0.00+000 0.00+000   0.00+000     8.44     8.36     0.00      632      262
   2        2        3     0.00+000 0.00+000 0.00+000 0.00+000   0.00+000     0.00   ******     0.00        0        0
            3        3     0.00+000 0.00+000 0.00+000 0.00+000   0.00+000     0.00   ******     0.00     1755      216
   3        4        3     0.00+000 0.00+000 0.00+000 0.00+000   0.00+000     0.00   ******     0.00    11928      429
            5        2     1.46+008 0.00+000 0.00+000 0.00+000   0.00+000     0.27    40.14     0.00       17       16
   4        6        2     4.71+008 0.00+000 0.00+000 0.00+000   0.00+000     0.87    26.91     0.00       52       44
            7        4     0.00+000 0.00+000 0.00+000 0.00+000   0.00+000     0.00   ******     0.00        0        0
   7        8        4     3.27+006 0.00+000 0.00+000 0.00+000   0.00+000     0.01     4.76     0.00     3057      441
           10        6     0.00+000 0.00+000 0.00+000 0.00+000   0.00+000     0.00   ******     0.00        0        0
   8       11        6     0.00+000 0.00+000 0.00+000 0.00+000   0.00+000     0.00   ******     0.00        0        0
            9        5     4.50+010 0.00+000 0.00+000 0.00+000   0.00+000    83.61     0.95     0.00     2626      800
  10
           12        6     0.00+000 0.00+000 0.00+000 0.00+000   0.00+000     0.00   ******     0.00        0        0
  11       13        6     0.00+000 0.00+000 0.00+000 0.00+000   0.00+000     0.00   ******     0.00        0        0
           18        6     0.00+000 0.00+000 0.00+000 0.00+000   0.00+000     0.00   ******     0.00        0        0
  12       19        6     0.00+000 0.00+000 0.00+000 0.00+000   0.00+000     0.00   ******     0.00        0        0
           16        6     5.13+008 2.90+008 2.09+009 1.18+009   2.46-001     0.95     9.83    13.89      709      204
  13       17        6     3.08+008 1.78+008 1.26+009 7.25+008   2.45-001     0.57     9.84     8.51      622      206
           14        6     5.35+008 3.03+008 2.17+009 1.23+009   2.46-001     0.99    10.28    14.49      748      200
  18       15        6     3.69+008 2.14+008 1.51+009 8.74+008   2.45-001     0.69     9.84    10.24      648      204
           22        6     5.45+008 3.07+008 2.22+009 1.28+009   2.46-001     1.01    10.41    14.71      796      204
  19       23        6     3.64+008 2.10+008 1.49+009 8.57+008   2.45-001     0.68    10.24    10.05      702      208
           20        6     6.40+008 3.63+008 2.60+009 1.48+009   2.46-001     1.19     9.63    17.37      814      209
           21        6     3.90+008 2.24+008 1.59+009 9.15+008   2.45-001     0.72     9.23    10.73      729      209
```

SAMPLE PROBLEM #2 - TEST RUN OUTPUT

```
                                                              MATERIAL RESULTS
MATERIAL TOTAL     SCALED    TOTAL     SCALED    MATERIAL PERCENT PERCENT    PERCENT TOTAL     TOTAL
TYPE     MATERIAL  MATERIAL  POWER     POWER     VOLUME   TOTAL   ERROR IN   SCALED  RAYS IN   SEGMENTS
NUMBER   POWER     POWER     DENSITY   DENSITY   USED     POWER   TOTAL PCT  POWER   MATERIAL  OF MAT.

      1  4.55+009  0.00+000  0.00+000  0.00+000  0.00+000    8.44     8.29     0.00      262         1
      2  6.14+008  0.00+000  0.00+000  0.00+000  0.00+000    1.14    22.76     0.00       55         2
      3  0.00+000  0.00+000  0.00+000  0.00+000  0.00+000    0.00  *******     0.00      429         3
      4  3.27+006  0.00+000  0.00+000  0.00+000  0.00+000    0.01     4.75     0.00      441         1
      5  4.50+010  0.00+000  0.00+000  0.00+000  0.00+000   83.61     0.94     0.00      500         1
      6  3.66+009  2.09+009  1.87+009  1.06+009  1.96+000    6.80     5.05   100.00      367        18



SUMMARY RESULTS

TOTAL ABSORBED POWER =  5.3873+010
TOTAL SCALED POWER   =  2.0892+009
TOTAL SOURCE POWER   =  5.3632+010
TOTAL NUMBER OF RAYS =         500
FINAL RANDOM INTEGER = 10939496209
EXECUTION TIME = 1095.469 SECONDS
```

APPENDIX A

A.1 HELIX

A.1.1 Introduction

This Appendix describes the procedure that is followed for finding the intersections of a ray with a helical pipe. Two related procedures for determining whether a given point is inside or outside of a given helical pipe and for determining the normal to a helical pipe at a given point on its surface are also discussed.

A.1.1.1 Notation and Conventions

The region R of interest in which the helical pipe lies has a fixed coordinate system. An equation like $\vec{V} = [x,y,z]$ means that $\vec{V}$ is a vector* with components x,y, and z. Vectors will be used to represent points, line segments, displacements of points and directions within the region R. The length of $\vec{V}$ is denoted by $|\vec{V}|$. $|[x,y,z]| = (x^2+y^2+z^2)^{\frac{1}{2}}$. Curves will be represented in parametric form. For example, if $\vec{P} = [x,y,z]$ and $\vec{D} = [\alpha,\beta,\gamma]$ is a direction (in which case $\alpha^2+\beta^2+\gamma^2 = 1$), then $\vec{L}(s) = \vec{P}+s\vec{D} = [x,y,z] + s[\alpha,\beta,\gamma] = [x+\alpha s, y+\beta s, z+\gamma s]$ is the line through $\vec{P}$ in the direction of $\vec{D}$. More precisely, it is the point on the line that is a distance s from the point $\vec{P}$. Similarly $\vec{H}(\theta) = [x+\rho\cos\theta, y+\rho\sin\theta, z+\kappa\theta]$ is a helix with axis parallel to the z-axis and passing through the point [x,y,z]. (More properties of the helix will be given in the following sections, particularly, the next.)

*The notation used is essentially that of Louis Brand, Vector Analysis, Wiley & Sons (1957) except that he uses hold face type instead of the arrow to denote vectors.

Surfaces will be represented in two ways: by parametric formulas and by locus equations. For example, the plane passing through the three points $\vec{P}_0$, $\vec{P}_1$, and $\vec{P}_2$ is given by the parametric formula

$$\vec{\pi}(u,v) = \vec{P}_0 + u\left(\vec{P}_1-\vec{P}_0\right) + v\left(\vec{P}_2-\vec{P}_0\right) \tag{A.1}$$

or the equation*

$$0 = \left(\vec{P}-\vec{P}_0\right) \cdot \left(\vec{P}_1-\vec{P}_0\right) \times \left(\vec{P}_2-\vec{P}_0\right) \tag{A.2}$$

which is satisfied by just those points that lie on the plane and no others.

A.1.2 The Helix

A parametric formula for a helix was given in A.1.1.1. With the addition of a subscript h on some of the terms, it is the one that will be used consistently in all that follows, viz.

$$\vec{H}(\theta) = \left[x_h + \rho\cos\theta, y_h + \rho\sin\theta, z_h + \kappa\theta\right] . \tag{A.3}$$

The axis of the helix is parallel to the z-axis and passes through the point $\vec{P}_h = [x_h, y_h, z_h]$. The radius of the circular cylinder on which the helix is wrapped is ρ. The pitch of the helix is $2\pi\kappa$, the distance traveled in the z direction per revolution. The helix is right-handed if $\kappa>0$. The parameter θ represents the angle of rotation required to move from the point $\vec{H}(0) = [x_h + \rho, y_h, z_h]$ to the point $\vec{H}(\theta)$.

*See Brand, §10 and 11 for definitions of scalar (dot) and vector (cross) products.

A.1.2.1 Tangent

The tangent[*] $\vec{t}(\theta)$ to the helix at the point $\vec{H}(\theta)$ is found by differention:

$$\vec{t}(\theta) = \frac{d}{d\theta}\vec{H}(\theta)$$

$$= \left[\frac{d}{d\theta}\left(x_h + \rho\cos\theta\right), \frac{d}{d\theta}\left(y_h + \rho\sin\theta\right), \frac{d}{d\theta}\left(z_h + \kappa\theta\right)\right] \qquad (A.4)$$

$$= [-\rho\sin\theta, \rho\cos\theta, \kappa] \quad .$$

The length of $\vec{t}(\theta)$ is the distance the point $\vec{H}(\theta)$ moves along the helix when θ increases by 1. The unit tangent $\vec{T}(\theta) = \vec{t}(\theta)/(\rho^2 + \kappa^2)^{\frac{1}{2}}$ is the unit vector in the direction of the tangent. It is the direction of the line tangent to the helix at $\vec{H}(\theta)$, so the parametric form for the tangent line is $\vec{H}(\theta) + s\vec{T}(\theta)$ where s, not θ, is the parameter.

A.1.2.2 Principal Normal

The principal normal[**] to a curve at any point is the direction from that point to the center of curvature. It is perpendicular to the tangent. It may be found by differentiating the tangent once again. Since $d\vec{t}(\theta)/d\theta = [-\rho\cos\theta, -\rho\sin\theta, 0]$, which has length ρ, the principal normal is $\vec{N}(\theta) = [-\cos\theta, -\sin\theta, 0]$. It is always perpendicular to the Z-axis as well as to $\vec{t}(\theta)$ and it points from $\vec{H}(\theta)$ toward the axis of the helix.

[*] See Brand, §27.

[**] Brand, §29.

The radius of curvature of the helix is given by

$$\rho_c = \frac{\left|\frac{d\vec{H}(\theta)}{d\theta}\right|^2}{\left|\frac{d^2\vec{H}(\theta)}{d\theta^2}\right|} = \rho + \kappa^2/\rho \quad , \tag{A.5}$$

which can be worked out by straightforward algebra and differentiation.

The binormal of a curve is the direction perpendicular to the tangent and the principal normal which may be determined by taking the vector product of those directions. In our case, the binormal is given by

$$\vec{M}(\theta) = \vec{T}(\theta) \times \vec{N}(\theta)$$

$$= \left[\kappa \sin\theta, -\kappa\cos\theta, \rho\right] \Big/ \left(\rho^2+\kappa^2\right)^{\frac{1}{2}} \quad . \tag{A.6}$$

A.1.3 The Helical Pipe

The surface that we must deal with is, loosely speaking, a circular cylinder whose axis is a helix which is to say that a plane perpendicular to the helix at some point $\vec{P}_h$ cuts the surface in the immediate vicinity of $\vec{P}_h$ in a circle with center $\vec{P}_h$ and radius a. A parametric formula for the surface can be given as

$$\vec{Q}(\theta,\phi) = \vec{H}(\theta) + a\cos\phi\,\vec{N}(\theta) + a\sin\phi\,\vec{M}(\theta)$$

$$= \Big[x_h + \rho\cos\theta - a\cos\phi\cos\theta + \kappa a\sin\phi\sin\theta/$$

$$\left(\rho^2+\kappa^2\right)^{\frac{1}{2}} , y_h + \rho\sin\theta - a\cos\phi\sin\theta - \kappa a\sin\phi\cos\theta/$$

$$\left(\rho^2+\kappa^2\right)^{\frac{1}{2}} , z_h + \kappa\theta + \rho a\sin\phi/\left(\rho^2+\kappa^2\right)^{\frac{1}{2}}\Big] \quad .$$

Notice that when $c=0$ the formula reduces to one for a circular cylinder of radius a and if $\kappa=0$ it reduces to one for a torus.

A.1.4 <u>The Ray and the Helical Pipe</u>

The origin of the ray will always be denoted by $\vec{P}_0 = [x_0,y_0,z_0]$ and its direction by $\vec{D} = [\alpha,\beta,\gamma]$ where, of course, $\alpha^2+\beta^2+\gamma^2 = 1$. We will always use $\vec{P}(s) = \vec{P}_0+s\vec{D}$ $=[x_0+s\alpha,y_0+s\beta,z_0+s\gamma]$ as the parametric formula for the ray where s denotes the distance from $\vec{P}_0$ to $\vec{P}(s)$. Since $\vec{P}_0$ is the origin of the ray, $s>0$ for points of the ray.

Let b denote the distance between the axis of the helix and line of the ray and let $\vec{P}(s_b)$ (it is possible that $s_b<0$) be the point which is closest to the axis. Since $\vec{D}$ is perpendicular to the shortest line joining $\vec{P}(s_b)$ to the axis, we must have $\alpha(x_h-x_0-s_b\alpha) + \beta(y_h-y_0-s_b\beta) = 0$. Therefore

$$s_b = \left[\alpha(x_h-x_0) + \beta(y_h-y_0)\right]/(\alpha^2+\beta^2) \qquad (A.7)$$

and

$$b^2 = (x_h-x_0-s_b\alpha)^2 + (y_h-y_0-s_b\beta)^2 \quad . \qquad (A.8)$$

As we soon will see, it is important to know whether the ray passes the axis on the right or left. The ray passes the axis on the right if and only if the three vectors $\vec{P}_0-\vec{P}_h$, $\vec{D}$ and $\vec{\kappa}$ form a basis for a right-handed coordinate system which, in turn, is true if and only if the triple product $\sigma = (\vec{P}_0-\vec{P}_h)\cdot(\vec{D} \times \vec{k})$ is positive. But

$$\vec{D} \times \vec{k} = [\alpha,\beta,\gamma] \times [0,0,1] = [\beta,-\alpha,0] \quad , \qquad (A.9)$$

and hence

$$\sigma = \left[x_0-x_h, y_0-y_h, z_0-z_h\right] \cdot [\beta,-\alpha,0] \qquad (A.10)$$

$$= \beta\left(x_0-x_h\right) - \alpha\left(y_0-y_h\right) \quad .$$

The magnitude, as well as the sign, of σ is significant. Notice that $\vec{D} \times \vec{k}$, being perpendicular to both $\vec{D}$ and $\vec{k}$, is parallel to the shortest segment joining $\vec{P}_h + s\vec{k}$ (the axis) to $\vec{P}_0+s\vec{D}$ (the ray). Hence, b must be the length of the projection of $\vec{P}_0-\vec{P}_h$ on $\vec{D} \times \vec{k}$,

$$b = \frac{\left|\left(\vec{P}_0-\vec{P}_h\right) \cdot \vec{D} \times \vec{k}\right|}{\left|\vec{D} \times \vec{k}\right|} = \frac{|\sigma|}{\left(\alpha^2+\beta^2\right)^{\frac{1}{2}}}$$

A.1.5 The Turns of the Helix

When the ray and the axis of the helix are skew, there is a unique plane Π_r containing the ray which is parallel to the axis. Consider, then, the half-plane extending away from the ray in a direction perpendicular to Π_r and having the axis as boundary. This half-plane cuts the helix into a series of individual loops, that we will call turns, whose endpoints are as far as possible from the plane Π_r. The turns are arcs of the helix $\vec{H}(\theta)$ corresponding to intervals $\psi_n \leq \theta \leq \psi_{n+1}$ where $\psi_n = \psi_0+2n\pi$, and

$$\sin \psi_0 = \left(y_h-y_0-\beta s_b\right)/b \qquad (A.12)$$

$$\cos \psi_0 = \left(x_h-x_0-\alpha s_b\right)/b \qquad (A.13)$$

The vector $[\cos \psi_0, \sin \psi_0, 0]$ is parallel to the shortest segment joining the axis to the ray, which is perpendicular to $\vec{D}$. Therefore

$$\alpha\cos \psi_0 + \beta\sin \psi_0 = 0 \qquad \text{(A.14)}$$

A.1.6 The Sequence of the Turns

The basis of the plan that is used for finding the first intersection is a procedure for calculating the intersections of a line with one turn of the helical pipe. For the sake of efficiency, it is desirable to know the order in which the turns are encountered by a point as it travels along the ray. The present section is devoted to the description of a method for plotting rays that is well-designed to illustrate how they proceed from turn to turn.

To see how the plot may be generated, consider a half-plane that is bounded on its edge by the axis of the helix and which cuts the ray at some point and let a curve be traced out on the half-plane by the cut-point as the half-plane rotates about its edge and the point travels along the ray.

Let $r(s)$ be the distance from the axis to $\vec{P}(s)$. Then,

$$r(s) = \left(\left(x_0 + \alpha s - x_h\right)^2 + \left(y_0 + \beta s - y_h\right)^2\right)^{\frac{1}{2}} \qquad \text{(A.15)}$$

$$= \left(b^2 + \mu^2\left(s - s_b\right)^2\right)^{\frac{1}{2}}$$

Let $w(s)$ be the distance from $\vec{P}(s)$ to the half-plane that passes through $\vec{P}(s_b)$.

Then

$$w(s) = \mu\left(s - s_b\right) \qquad (A.16)$$

where

$$\mu = \left(\alpha^2+\beta^2\right)^{\frac{1}{2}} \operatorname{sgn}(\sigma) \qquad (A.17)$$

i.e., μ is the length of the projection of $\vec{D}$ on the plane $z=0$ and it is positive if the ray passes the axis on the right as it does in Fig. A.2. It follows from Eqs. (A.10) and (A.11) that

$$\mu = \sigma/b \quad . \qquad (A.18)$$

Finally, let

$$\phi(s) = \arctan w(s)/b \qquad (A.19)$$

and

$$z^*(s) = z_0 + \gamma s - \kappa\phi(s). \qquad (A.20)$$

The significance of $\phi(s)$ is shown in Fig. A.2. It is the angle that the plane through P(s) makes with the plane through $P(s_b)$. The sign of μ in Eq. (A.17) was selected so that ϕ and θ are both measured in the right-handed or counter-clockwise sense. The purpose of $\phi(s)$ is to provide the term $\kappa\phi(s)$ in Eq. (A.20) which compensates for the rise (or fall) of the helix as the point on the ray passes the axis. Thus $z^*(s)$ represents the height of $\vec{P}(s)$ above a level that rises with the helix. The desired plot, then, is generated by a point having r(s) as ordinate and $z^*(s)$ as abscissa. On this plot, the turns of the helix appear as fixed points with coordinates (r_n, z^*_n) where $r_n = a$ and $z^*_n = z_h + \kappa(\phi_0 + (2n+1)\pi)$.

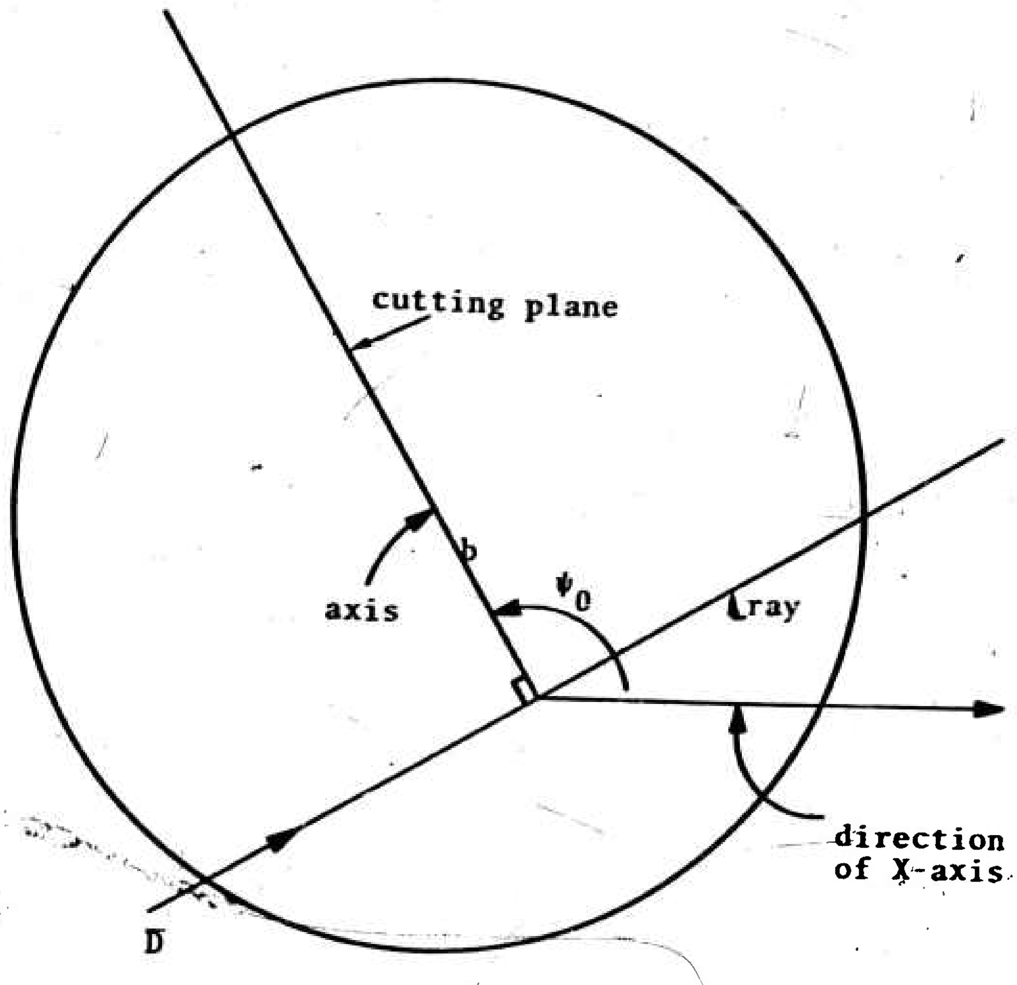


Figure A.1 A view of the helix and ray looking down the axis of the helix.

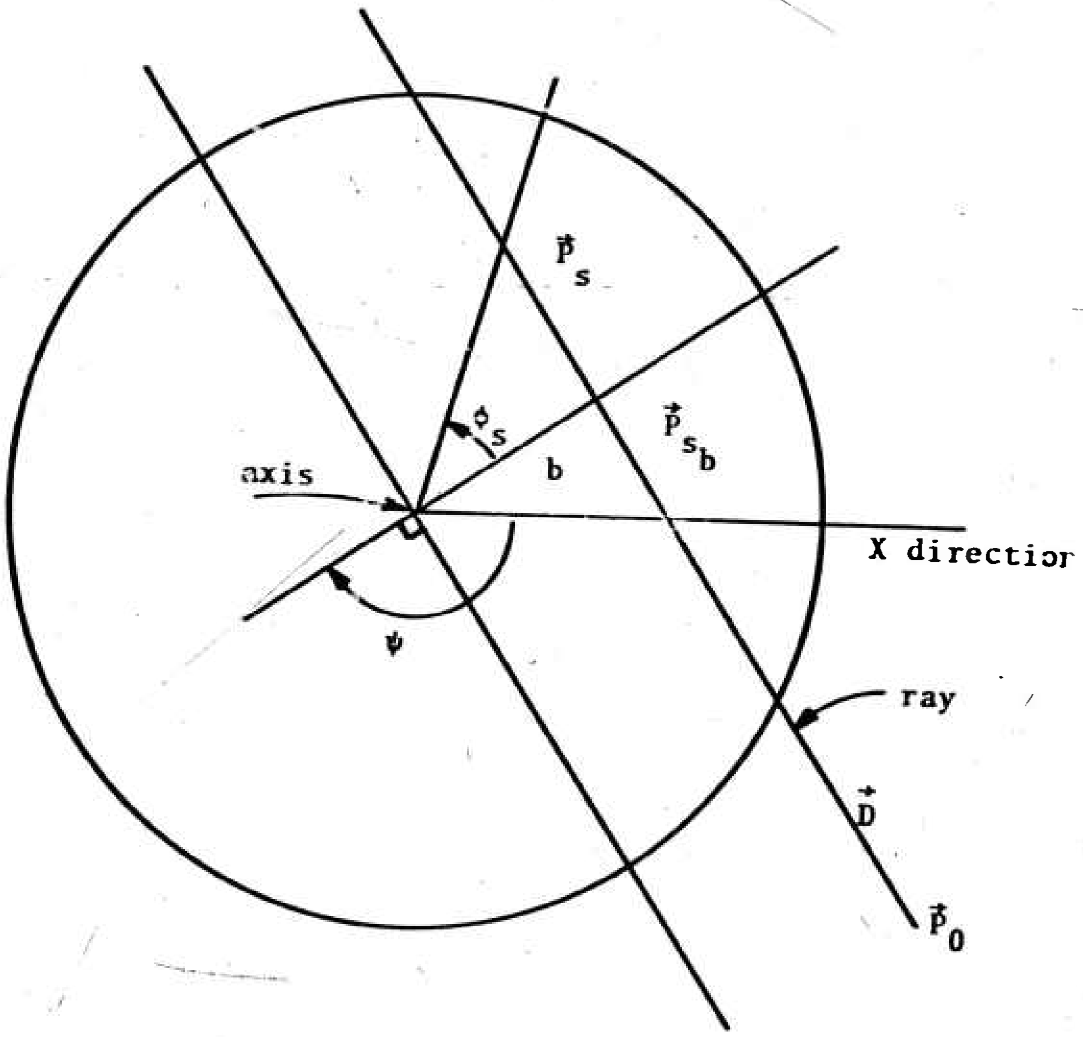


Figure A.2 Another top view of the helix and ray.

The equation of the trace of the ray is obtained by eliminating s from Eqs. (A.15) and (A.20). When $\kappa=0$ the result is

$$\left(\frac{z^*-z_b}{\gamma b}\right)^2 - \left(\frac{r}{\mu b}\right)^2 = 1 \qquad \text{(A.21)}$$

where $z_b = z_0 + s_b$, so that the trace is a hyperbola whose center has coordinates $z^* = z_b$ and $r = 0$. The effect of $k \neq 0$ depends on the relative values of $\kappa\mu/\gamma$ and b. If $\kappa\mu/\gamma<0$ then ~~the ray~~ goes counter to the helix and the hyperbola is stretched by the amount $\pi\kappa$, the distance the helix rises during a half-turn. In this case, the ray meets the turns of the helical pipe in their natural sequence.

If $\kappa\mu/\gamma>0$ then the ray and the helix both rise or both fall and if the magnitude of κ is large enough so that $\kappa\mu/\gamma>b$ then helix rises or falls faster than the ray while the ray is close to the axis; the hyperbola is compressed by $\pi\kappa$ and a loop forms.

To verify this fact, observe that

$$\begin{aligned} dz^*(s)/ds &= \gamma - \frac{\kappa\mu b}{\mu^2(s-s_b)^2 + b^2} \\ &= \gamma\left\{1 - \frac{\frac{\kappa\mu}{\gamma b}}{\left\{\frac{\mu(s-s_n)}{b}\right\}^2 + 1}\right\} \end{aligned} \qquad \text{(A.22)}$$

which changes sign if $\kappa\mu/\gamma>b$ at $s=s_b\pm\lambda$ where

$$\lambda = \sqrt{\frac{b}{\mu^2}\left(\frac{\kappa\mu}{\gamma} - b\right)} \qquad \text{(A.23)}$$

When $0<\kappa\mu/\gamma<b$, the hyperbola is still compressed by $-\kappa$ but not enough to form a loop.

Figure A.3 shows examples of the three types of traces that rays may have. The traces of the turns of the helical pipe are more or less elliptical. It is seen that when $\kappa\mu/\gamma<b$, the ray intersects the turns consecutively, each one at most twice. When $b<\kappa\mu/\gamma$, all turns except the two nearest $z^*=z_b$ are still passed in natural sequence and each is intersected at most twice. On the other hand, the two exceptional turns (i.e., the two with z^* nearest z_b), may both be intersected four times by a ray whose trace resembles the one pictured in Figure A.3.

A.1.7 Numbering the Turns

The strategy that is used to find the first intersection of a ray with a helical pipe is to determine the sequence in which the ray approaches successive turns and then to examine the turns in that sequence to find the first that is actually intersected. In implementing this strategy, the turns are assigned ordinal numbers as follows.

Let

$$\nu = 2\pi \operatorname{sgn}(\kappa\gamma) \quad , \quad \phi_n = \phi_0 + n\nu$$

where

$$\cos \phi_0 = (y_h - y_0 - \beta s_b)/b$$

and

$$\sin \phi_0 = (y_h - s_0 - \alpha s_b)/b$$

Then, turn n is the turn for which $\phi_n<\theta<\phi_{n+1}$.

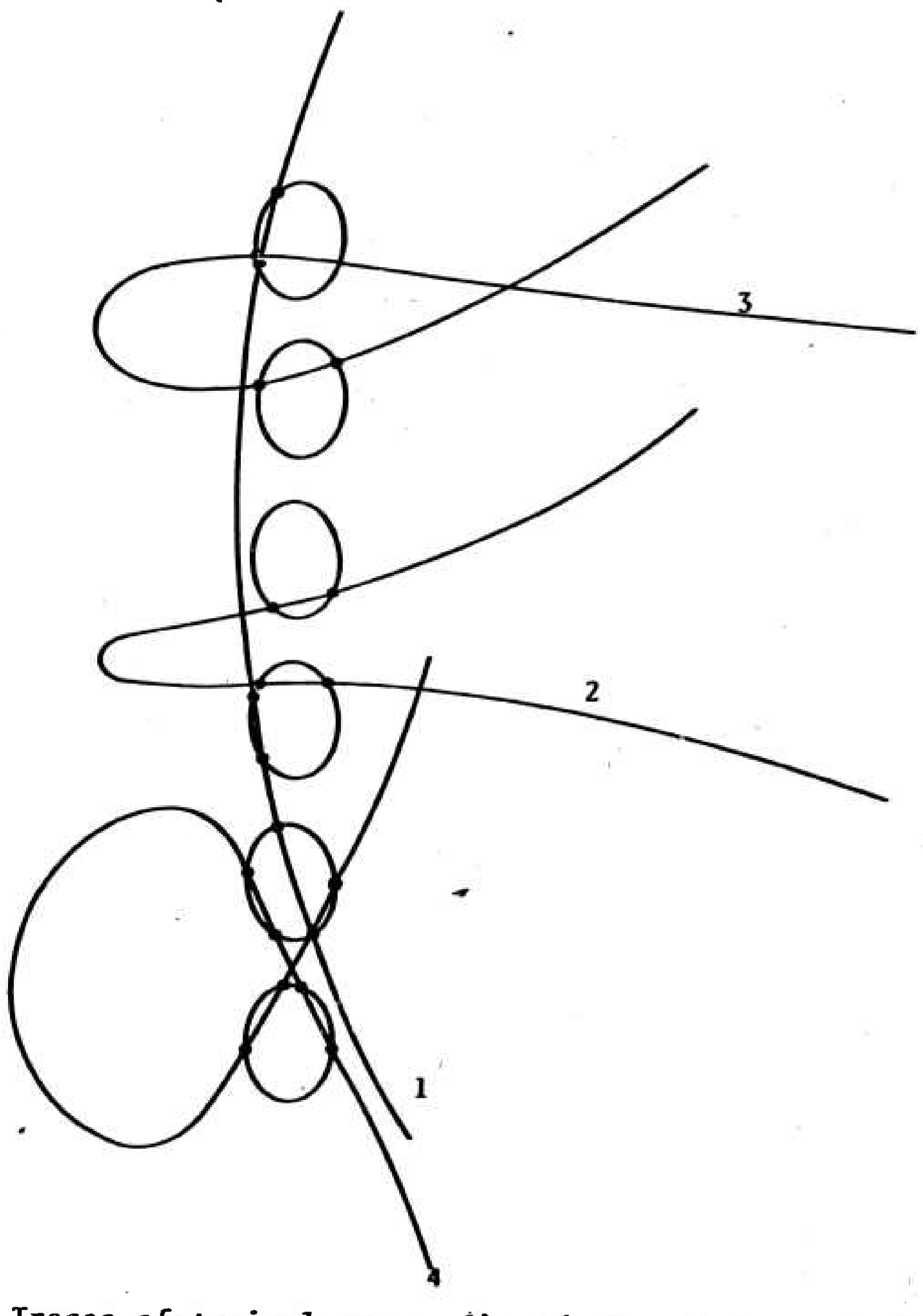


Figure A.3 Traces of typical rays: 1) $\kappa\mu/\gamma<0$, 2) $0<\kappa\mu/\gamma<b$, 3) $b<\kappa\mu/\gamma$, 4) ray with 8 intersections

This definition of the number of a turn differs from that of A1.5 in that here we require that the sign of ν agree with that of $\kappa\gamma$. This has the pleasant effect of insuring that n will increase as s increases (except for that segment of the ray corresponding to a loop in the trace). In order to give precision to the above statement, the function n(s) is defined to be the number of the loop that is closest to the point $\vec{P}(s) = \vec{P}_0 + s\vec{D}$. The value of n which is assigned to points midway between turns is unimportant since such points are necessarily exterior to the helical pipe.

A.1.8 Seven Special Points on a Ray

There are certain points on a ray that are special enough to receive specific names. They are listed below together with a formula for the value s at which the point is attained. When the value of s for some special point on a particular ray is negative or complex, it means that that point does not occur. The points are

P_0, the origin of the ray. $s_0 = 0$

P_1, the point where the ray enters the cylinder that encloses the pipe. $s_1 = s_b - \sqrt{(\rho+a)^2-b^2}$. If $b>\rho+a$, the ray does not penetrate the cylinder.

P_2, the point where the ray enters the cylinder on which the pipe is wrapped. $s_2 = s_b - \sqrt{(\rho-a)^2+b^2}$. If $b>\rho-a$, the ray does not penetrate the inner cylinder.

P_3, the point where the ray emerges from the inner cylinder. $s_3 = s_b + \sqrt{(\rho-a)^2+b^2}$.

P_4, the point where the ray emerges from the outer cylinder. $s_4 = s_b + \sqrt{(\rho+a)^2+b^2}$.

P_5, the point where the ray reaches the bottom of the loop in its trace. $s_5 = s_b+\lambda$. There is no loop if λ is complex.

P_6, the point where the ray reaches the top of the loop in its trace. $s_6 = s_b-\lambda$.

The number of the turn nearest P_k is $n_k = n(s_k)$. Note that

$$s_1 \le s_2 \le s_3 \le s_4 \; , \; s_5 \ge s_6$$

$$n_1 \le n_2 \le n_3 \le n_4 \; , \; n_5 \le n_6$$

whenever the indicated quantities are real.

The subroutine IXTHEL which we consider next is not exactly simple but it is straightforward. The complications that arise have to do with the singularities that arise when one or more of the quantities γ, μ and b become too small. It will be observed that when $n_6>n_5$ these two turns are treated simultaneously because they can generate interlocking intersections.

A.1.9 The Distance from a Point to a Line

The distance from the point $\vec{P} = [x,y,z]$ to the line $\vec{L}(s) = \vec{P}_0+s\vec{D} = [x+\alpha s,\ y+\beta s,\ z+\gamma s]$ is attained where $\vec{D}\cdot(\vec{L}(s)-\vec{P}) = 0$, i.e., the segment that joing $\vec{P}$ to the closest point on $\vec{L}$ is perpendicular to the line. If $s=s_m$ at that point, then

$$s_m = \frac{\vec{D}\cdot(\vec{P}_0-\vec{P})}{\vec{D}\cdot\vec{D}}$$

$$= \alpha(x_0-x) + \beta(y_0-y) + \gamma(z_0-z)$$

and the distance from the point to the line is

$$d = \left[\left(x_0 + \alpha s_m - x\right)^2 + \left(y_0 + \beta s_m - y\right)^2 + \left(z_0 + \gamma s_m - z\right)^2\right]^{\frac{1}{2}} \qquad (A.25)$$

A.1.10 The Distance from a Point to a Turn

It is often necessary to determine the distance from a given point to a given turn of the helix. The distance from $\vec{P} = [x,y,z]$ to $\vec{H}(\theta)$ is easily verified to be $(2G)^{\frac{1}{2}}$ where

$$G = \tfrac{1}{2}\left(x-x_h- \cos\,\theta\right)^2 + \tfrac{1}{2}\left(y-y_h- \sin\,\theta\right)^2 + \tfrac{1}{2}\left(z-z_h-\kappa\theta\right)^2 \quad . \qquad (A.26)$$

A change of θ will reduce the distance if it will reduce G. The distance will be a minimum when $dG/d\theta = 0$ and $d^2G/d\theta^2 > 0$. The first two derivatives of B turn out to be

$$\frac{dG}{d\theta} = \rho\sin\,\theta\left(x-x_h-\rho\cos\,\theta\right) - \rho\cos\,\theta\left(y-y_h-\rho\sin\,\theta\right) - \kappa\left(z-z_h-\kappa\theta\right)$$
$$= \rho\sin\,\theta\,\left(x-s_h\right) - \rho\cos\,\theta\left(y-y_h\right) - \kappa\left(z-z_h-\kappa\theta\right) \qquad (A.27)$$
$$\frac{d^2G}{d\theta^2} = \rho\cos\,\theta\left(x-x_h\right) + \rho\sin\,\theta\left(y-y_h\right) + \kappa^2 \quad .$$

The problem reduces to that of finding the nearest root of $dG/d\theta$. A given estimate of the θ of the closest point is improved using Newton's method which is to set

$$\theta_{new} = \theta - \frac{\frac{dG}{d\theta}}{\frac{d^2G}{d\theta^2}} \quad . \qquad (A.28)$$

It is well-known that Newton's method can fail and the present application is no exception. The trouble arises when $d^2G/d\theta^2 < 0$ which usually causes a maximum rather than a minimum to be approached. The problem is overcome by setting $\theta_{new} = \theta - \mathrm{sgn}(dG/d\theta)$ whenever $d^2G/d\theta^2 < 0$, i.e., by moving one radian toward the minimum.

The question of when to stop this iterative approach to the minimum cannot be answered out of context and therefore we leave it to be discussed when it occurs in a specific application.

A.1.11 The Inside of the Pipe

It is sometimes necessary to know if a given point $\vec{P} = [x,y,z]$ is inside or outside the pipe. The point $\vec{P}$ is inside or outside the pipe. The point $\vec{P}$ is inside if its distance from the helix is less than a. This assertion follows from the definition of the surface of the pipe which, according to the parametric formula given in A.1.3, consists of those points lying at a distance a from the helix. Thus the problem reduces to finding the distance from $\vec{P}$ to the helix.

The first step in the procedure for finding the distance is to find the values of θ for those points where the helix intersects the half-plane that is bounded by the axis and contains the point $\vec{P}$. These θ-values are

$$\theta_n = \mathrm{ATAN2}\left(y-y_h,\ x-x_h\right) + 2\pi n \quad . \tag{A.29}$$

The value of n which minimizes $|\vec{P}-H(\theta_n)|$ is the one that minimizes $|z-z_h-\kappa\partial|$ which is, in turn

$$n = \left[\frac{z-z_h-\kappa\theta_0}{2\pi\kappa} + \tfrac{1}{2}\right] \tag{A.30}$$

where [x] denotes the greatest integer that is not greater than x. Caution: in FORTRAN, INT(x) = [x]+1 when x<0.

Using $\vec{H}(\theta_n)$ as a starting point, a procedure like that of A1.10 is used to search for the closest point with the refinement of a quadratic term. Thus

$$\frac{d^3G}{d\theta^3} = -\rho\sin\theta\left(x-x_h\right) + \rho\cos\theta\left(y-y_h\right) \qquad \text{(A.31)}$$

and we write

$$0 = \frac{dG}{d\theta} + \left(\theta_{new}-\theta\right)\frac{d^2G}{d\theta^2} + \frac{\left(\theta_{new}-\theta\right)^2}{2}\,\frac{d^3G}{d\theta^3} \qquad \text{(A.32)}$$

Writing G', G", G"' for the successive derivatives of G and δ for $\theta_{new}-\theta$, we get

$$\delta = \frac{-G'' + \left((G'')^2 - 2G'G'''\right)^{\frac{1}{2}}}{2G'''} \qquad \text{(A.33)}$$

$$= \frac{-G'}{\left((G'')^2 - 2G'G'''\right)^{\frac{1}{2}}}$$

The second form, which is obtained from the first by rationalizing the numerator, is preferred, especially when G"' is small.

The iteration may well be stopped when $|S|<.01$ because the error will be less than $a(1-\cos\delta) < .5\times10^{-4}a$.

The method fails for points on the axis but these points are outside the pipe because $a<\rho$.

A.1.12 The Distance from the Ray to a Turn

A ray approaches every turn at least once and never more than twice. If it approaches turn n at two points, θ_a and θ_b then θ_a and θ_b will be separated by $\psi_n + \frac{1}{2}\nu$, the mid-point of the turn

The procedure for finding where and how often a particular turn approaches a ray is a combination of techniques described above. First, the point $\theta_1 = \psi_n + \frac{1}{4}\nu$ is selected. The equation (A.24) is used to find the point on the ray closest to $\vec{H}(\theta)$. Let its parameter be called $s(\theta_1)$. Next the method discussed in A1.10 is applied to find a θ_2 such that $\vec{H}(\theta_2)$ is closer to $\vec{P}(s(\theta_1))$ than $\vec{H}(\theta_1)$ and then $s(\theta_2)$ is calculated. The process is repeated until a convergence criterion is satisfied. When the procedure was first designed, the plan was to apply just one step of the algorithm described in A1.10 per iteration but certain test cases showed signs of instability. The dynamics of the instability are not understood but it was found that repeating the algorithm until $|\theta_{new} - \theta| < .01$ was sufficient to damp the oscillations.

The whole procedure is repeated with $\theta_1 = \psi_n + \frac{3}{4}\nu$. When the ray approaches the turn on both sides of $\psi_n + \frac{1}{2}\nu$, the points of closest approach are found with an accuracy of better than .01 in θ. If the ray approaches the turn on only one side, the procedure on both sides will usually converge to that point but occasionally , when θ_1 is set to the "wrong" side, it will drift around the back of the helix to an adjacent turn.

A.1.13 Finding the Intersections

If a ray is found to be within a distance a of a turn at a point where it is closest, it can be inferred that it intersects that turn. Two procedures are used for localizing intersections, one is used if $|\vec{D}\cdot\vec{T}(\theta)|<0.3$, else the other is used.

In case $|\vec{D}\cdot\vec{T}(\theta)|<0.3$, a first approximation to the location of the intersections is made by calculating the intersection of the ray with a circular cylinder of radius a and axis through $\vec{H}(\theta)$ in the direction $\vec{T}(\theta)$. If c is the distance from $\vec{H}(\theta)$ to the ray then the intersection of the ray with the cylinder will be at $s(\theta)\pm\Delta s$ where

$$\Delta s = \left(\frac{a^2-c^2}{1-(\vec{D}\cdot\vec{T})^2}\right)^{\frac{1}{2}} \tag{A.34}$$

The first approximations to the intersections of the ray with the turn of pipe are further refined. Let $\vec{P}_a = [x_a,y_a,z_a]$ denote one of the first approximants. The procedure begins with the application of A1.10 to determine the θ corresponding to the point on the helix that is closest to the point P_a. Then the closer intersection of the ray to the tangent cylinder at the new θ is determined. The equations used are discussed below. First, the equation of the cylinder is

$$|\vec{P}-\vec{H}(\theta)|^2 = a^2 + \left((\vec{P}-\vec{H}(\theta))\cdot\vec{T}(\theta)\right)^2 \tag{A.35}$$

Next, we substitute $\vec{P}_a+u\vec{D}$ for $\vec{P}$ in Eq. (A.35) and solve for u, which yields

$$u^2\left(1-(\vec{D}\cdot\vec{T})^2\right) + 2u\vec{D}\cdot\left(\vec{P}_a-\vec{H}\right) + |\vec{P}_a-\vec{H}|^2 - a^2 = 0 \tag{A.36}$$

or

$$u = \frac{a^2 - c^2}{b\left(1 + \left(1+d\left(a^2-c^2\right)/b^2\right)^{\frac{1}{2}}\right)} \qquad (A.37)$$

where

$$c^2 = |\vec{P}_0-\vec{H}|^2 \ , \quad d - 1 - (\vec{D}\cdot\vec{T})^2 \ , \quad b = \vec{D}\cdot\left(\vec{P}_a-\vec{H}\right)$$

and $\vec{T}\cdot(\vec{P}_0-\vec{H}) = 0$ (because the segment joining $\vec{P}_0$ to the helix at $\vec{H}$ is perpendicular to the tangent $\vec{T}$).

Then s+u is substituted for s and θ is further refined. If the change in θ is less than .01, the current value of s is accepted, else another step is taken.

When $|\vec{D}\cdot\vec{T}|>.7$, the approximation in Eq. (A.35) will often yield such poor accuracy that the refinement technique fails. For that reason, an entirely different method is used when $|\vec{D}\cdot\vec{T}|$ is large. The criterion for the alternate method is $|\vec{D}\cdot\vec{T}|>.3$.

In the beginning of this section, s(θ) was defined to be the value of the parameter of the point on the ray closest to $\vec{H}(\theta)$. We now define a new point on the ray to be associated with θ; and that is the point where the ray intersects the plane Π(θ) that is normal to $\vec{T}(\theta)$ and is cut by the helix at $\vec{H}(\theta)$. The equation for Π(θ)

$$\vec{P}\cdot\vec{T}(\theta) = \vec{H}(\theta)\cdot\vec{T}(\theta) \qquad (A.38)$$

substituting $\vec{P}_0+s\vec{D}$ for $\vec{P}$ in Eq. (A.38) yields an equation in s, the parameter of the desired point:

$$\left(x_0+\alpha s\right)(-\rho\sin\theta) + \left(y_0+\beta s\right)\rho\cos\theta + \left(z_0+\gamma s\right)\kappa$$

$$= \left(x_h+\rho\cos\theta\right)(-\rho\sin\theta) + \left(y_0+\rho\sin\theta\right)\rho\cos\theta + \left(z_h+\kappa\theta\right)\kappa$$

Denoting the solution by $s_p(\theta)$, we get

$$s_p(\theta) = \frac{\left(x_h-x_0\right)(-\rho\sin\theta) + \left(y_h-y_0\right)\rho\sin\theta + \left(z_h-z_0+\kappa\theta\right)\kappa}{-\alpha\rho\sin\theta + \beta\rho\cos\theta + \gamma\kappa} \tag{A.39}$$

Note that the denominator of the RHS of Eq. (A.39) is $(\rho^2+\kappa^2)^{\frac{1}{2}}\vec{D}\cdot\vec{T}$, making $s_p(\theta)$ large when $\vec{D}\cdot\vec{T}$ is small. The important thing about the point $\vec{P}(s_p(\theta))$ is that $\vec{H}(\theta)$ is locally the closest point on the helix. Therefore, $\vec{P}(s_p(\theta))$ is a point of intersection if the distance $|\vec{P}(s_p(\theta))-\vec{H}(\theta)| = a$.

Let $B(\theta)$ be defined as

$$\begin{aligned} B(\theta) &= \tfrac{1}{2}\left(x_0+\alpha s_p(\theta) - x_h - \rho\cos\theta\right)^2 \\ &+ \tfrac{1}{2}\left(y_0+\beta s_p(\theta) - y_h - \rho\sin\theta\right)^2 \\ &+ \tfrac{1}{2}\left(z_0+\gamma s_p(\theta) - z_h - \kappa\theta\right)^2 \quad , \end{aligned} \tag{A.40}$$

or, in vector notation, $B(\theta) = \frac{1}{2}|\vec{P}(s_p(\theta))-H(\theta)|^2$ or, in words, half the square of the distance from $\vec{P}(s_p(\theta))$ to $\vec{H}(\theta)$. Thus the problem of finding intersections reduces to that of solving the equation

$$B(\theta) = \frac{a^2}{2} \quad . \tag{A.41}$$

When $|\vec{D}\cdot\vec{T}(\theta)| << a$, Eq. (A.41) is hard to solve because $B(\theta)$ becomes very large in the vicinity of the root and consequently the cylinder approximation is employed in such cases.

A.1.14 Finding the Roots of $B(\theta) = a^2/2$

The process of finding the roots of Eq. (A.41) involves $dB/d\theta$ which we denote by B', as well as B itself. The formula B' follows from Eq. (A.);

$$\begin{aligned} B'(\theta) = &\left(x_0+\alpha s_p(\theta) - x_h - \rho\cos\theta\right)\left(\alpha s_p'(\theta) + \rho\sin\theta\right) \\ &+ \left(y_0+\beta s_p(\theta) - y_h - \rho\sin\theta\right)\left(\beta s_p'(\theta) - \rho\cos\theta\right) \\ &+ \left(z_0+\gamma s_p(\theta) - z_h - \kappa\theta\right)\left(\gamma s_p'(\theta) - \kappa\right) \end{aligned} \tag{A.42}$$

where

$$s_p'(\theta) = \left(DN'-ND'\right)/D^2 \tag{A.43}$$

$$N = \left(x_h-x_0\right)\left(-\rho\sin\theta\right) + \left(y_h-y_0\right)\rho\cos\theta + \left(z_h-z_0+\kappa\theta\right)\kappa \tag{A.44}$$

$$N' = \left(x_h-x_0\right)\left(-\rho\cos\theta\right) + \left(y_h-y_0\right)\left(-\rho\sin\theta\right) + \kappa^2 \tag{A.45}$$

$$D = -\alpha\rho\sin\theta + \beta\rho\cos\theta + \gamma\kappa \tag{A.46}$$

$$D' = -\alpha\rho\cos\theta - \beta\rho\sin\theta \tag{A.47}$$

The procedure is to examine $B(\theta)$ and $B'(\theta)$ at steps of about $\pi/4$ looking for intervals that might contain one or more roots. When a change in the sign of $B(\theta)-a^2/2$ is observed between the endpoints of an interval, a rather ordinary root finder is evoked to find the location of the location of the intersection to the desired accuracy. But a sign change in $B(\theta)-a^2/2$ will occur only when a single root lies within the interval. Two indicators are used to detect the occurrence of double roots. The first is a sign change in B'. If B' changes sign as an interval is traversed, then an extremum in B must occur within the interval. The extremum is ignored if it is in the wrong direction, e.g., if it is a maximum and B is greater than $a^2/2$ at the end-points. But if the extremum is in the right direction, a linear interpolation of B' is applied to provide an estimate of θ at the extreme point. If B is on the other side of $a^2/2$ at the estimated extreme point, then two roots are bracketed and the root-finder is called forth for each. Otherwise, the reduction of $|B-a^2/2|$ is computed and if it is reduced by more than 1/2, the interpolation is repeated, if not, the interval is abandoned.

The second indicator of a double root is used to detect intervals in which a double sign change of B' has occurred. The quantity that is tested is

$$c = \frac{B(\theta_1) - B(\theta_2)}{(\theta_1-\theta_2)\left(B^1(\theta_1) + B^1(\theta_2)\right)} \qquad \text{(A.48)}$$

where θ_1 and θ_2 are the values of θ at the end points of the interval. Thus, c is the ratio of the difference quotient of B to twice the average of the derivatives at the endpoints. For a quadratic, $c = 1/2$. If $c<1/4$, the interval is considered to be too large and it is subdivided. The subintervals are then processed in the same way as full-sized intervals.

In the above, it has been assumed that no interval can contain more than two roots of $B-a^2/2$. To be sure that such is the case, each turn is divided in the middle into two half-turns which are treated separately. Each half-turn contains at most two roots and at most one minimum of B'. The latter fact is also used to reduce the number of branches at a few points in the program.

The techniques described above would occasionally fail in intervals containing a zero in the denominator of the RHS of Eq. (A.39) for $s_p(\theta)$. The point to be avoided is found by solving the equation $D(\theta) = 0$ where D is defined by equation (A.46) The solution is simplified by substituting $\theta_0+\zeta$ for θ where $\theta_0 = \psi_n+\frac{1}{2}\nu$. Then

$$D = -\alpha\rho\sin\left(\theta_0+\zeta\right) + \beta\rho\cos\left(\theta_0+\zeta\right) + \gamma\kappa$$

$$= -\alpha\rho\sin\theta_0\cos\zeta - \alpha\rho\cos\theta_0\sin\zeta$$

$$+ \beta\rho\cos\theta_0\cos\zeta - \beta\rho\sin\theta_0\sin\zeta + \gamma\kappa$$

Now $\frac{1}{2}\nu = \pm\pi$ so $\cos\theta_0 = -\cos\psi_n = -\cos\psi_0$ and $\sin\theta_0 = -\sin\psi_n = -\sin\psi_n$. It then follows from Eq. (A.14) that $\alpha\cos\theta_0 + \beta\sin\theta_0 = 0$. Therefore, when $D = 0$

$$\cos\zeta = \frac{\gamma\kappa}{\rho\left(\alpha\sin\theta_0 - \beta\cos\theta_0\right)} = -\frac{\gamma\kappa}{\rho\mu} \qquad \text{(A.49)}$$

If $|\gamma\kappa/\rho\mu|>1$, then $\vec{t}(\theta)$ is never perpendicular to $\vec{D}$, but otherwise, $\vec{D}\cdot\vec{t}(\theta) = 0$ for $\theta=\theta_0\pm\zeta$. At those two points, $s_p(\theta)$ and $B(\theta)$ become infinite and the plane $\Pi(\theta)$ defined by Eq. (A.38) becomes parallel to the ray. To determine which side of $\Pi(\theta_0+\zeta)$ contains the ray, we calculate $d_1\equiv\vec{t}(\theta_0+\zeta)\cdot(\vec{P}_0-\vec{H}(\theta_0+\zeta))$ which is the distance from the plane to the ray except that d_1 is positive or negative according as the ray is or is not on the side of $\Pi(\theta_0+\zeta)$ to which $\vec{t}$ points.

The next question is how close to $\theta_0+\zeta$ can the intersection (if any) come. The following approximation will be adequate for our purposes. Recall that the radius of curvature of the helix is $\rho+\kappa^2/\rho$. The intersection might be as far as $\rho+a$ from the axis or $\rho+a+\kappa^2/\rho$ from the center of curvature which would minimize the distance from $\theta_0+\zeta$ to the intersection. In that case, if the plane moves a distance d_1 to go from $\theta_0+\zeta$ to the intersection, θ must change by more than

$$\theta_{\min} = \frac{\rho+\kappa^2/\rho}{\rho+a+\kappa^2/\rho}\,\frac{d_1}{\left(\rho^2+\kappa^2\right)^{\frac{1}{2}}} = \frac{d_1\left(\rho^2+\kappa^2\right)^{\frac{1}{2}}}{\rho^2+\kappa^2+\rho a} \tag{A.50}$$

where $(\rho^2+\kappa^2)^{\frac{1}{2}} = |\vec{t}(\theta)| = |d\vec{H}(\theta)/d\theta|$, the distance a point on the helix moves per radian increase in θ. Thus, of $\theta_{\min}>0$ we look for intersections between $\theta_0+\zeta+\theta_{\min}$ and $\theta_0+\pi$ and if $\theta_{\min}<0$ we look between θ_0 and θ_0 and $\theta_0+\zeta+\theta_{\min}$. In either case, $B(\theta)$ is well-behaved over the range.

Similar considerations apply to $\theta_0-\zeta$. It should be emphasized that if $\theta_{\min}$ is very small, then $\vec{D}\cdot\vec{T}$ is small and the problem of searching for roots of $B(\theta)$ are avoided by using the cylinder approximation.

A.1.15 Assembling the Pieces

Having considered all the components of the procedure for finding the first intersection of a ray with a helical pipe, we proceed to describe how they are put together. The flow of the calculation goes as follows.

A.1.15.1 Step 1

Fundamental constants $(b,\mu,\lambda\ldots)$ are computed. Six special values s_i, $1\leq i\leq 6$ of the parameter s are evaluated together with $n_i=n(s_i)$ and $n_0 = n(0)$. The number n of the first turn to be investigated is selected using the following decision rules.

1. if $s_1>0$ set $n = n_1$
2. if $s_1<0<s_2$ set $n = n_0$
3. if $s_2<0<s_3$ set $n = n_3$
4. if $s_3<0<s_4$ set $n = n_0$
5. if $s_4<0$ then there is no intersection
6. if $n=n_6$ as set by one of the above, change n to n_5.

A.1.15.2 Step 2

Having selected a turn for investigation, the method of A1.12 is applied to determine whether the line of the ray comes close enough to either half of the turn to intersect the pipe. If so, go to step A.1.15.4 otherwise go to step A.1.15.3.

A.1.15.3 Step 3

It has been established that there is no intersection with turn n ($s<0$ does not count).

1. if $n=n_5<n_6$, set $n=n_6$ and go to A.1.15.2 otherwise, set $n=n+1$ and continue.

2. if $n>n_4$ there is no intersection.

3. If $n_2<n<n_3$, set $n=n_3$.

4. Go to step A.1.15.2

A.1.15.4 Step 4

An intersection has been identified. The value of $\vec{D}\cdot\vec{T}$ is determined at the closest known pair of points between the ray and the half-turn and on that basis, the B-method or the cylinder approximation is used to determine the location s^* of the intersection to within an acceptable tolerance. If $0<s^*<s^{**}$ where s^{**} is the best previously determined intersection (initially; $s^{**} = 10^{21}$) then set $s^{**}=s^*$. Both half-turns are conside. d. If $n=n_5<n_6$ then set $n=n_6$ and repeat this step. Otherwise, one or more intersections with $s>0$ have been found and the procedure for ordering the turns for consideration assures us that the minimum of these positive s's must correspond to the first intersection.

APPENDIX B

B.1 AUTOMATIC SEGMENTATION

A separate computer program has been developed to automatically segment a generalized circular cylinder. The code is called LAZY and produces data input cards for the ZAP code.

It is assumed that the cylinder is homogeneous and is confined between two end planes. The outer surface of the cylinder and the two parallel end planes are considered to be Fresnel's reflection. All internal cylinders and planes are treated as dummy boundaries.

Either a full or half cylinder may be generated. If a half cylinder is used, the plane through the center of the cylinder is treated as a plane of symmetry.

An option exists for treating a cylindrical shell. In this case the segments are those confined between an outer cylinder and an inner cylinder.

The segments are formed by generating a specified number of equally spaced planes between and parallel to the two end planes, and a specified number of concentric cylinders within the outer and inner cylinders. In addition, planes are generated at equal angles through and parallel to the cylinder axis. In this way each segment is confined by four planes and one or two cylinders.

In addition to generating boundary and segment cards, the program will generate structure data cards.

The cards generated by the program will be only a portion of the cards needed to set up a ZAP problem and are intended primarily as a means to segment the laser rod.

B.2 INPUT FOR LAZY

Input to the LAZY code is in the form of data cards. Standard Fortran Data keypunch forms are used and formats are 12I6 and 6E12.4.

Output from the code consists of punched cards and a listing of the card images.

Care must be taken that no plane passes through the origin.

Card #1 (12I6)

1) IOPSYM = Option for generating only half of a cylinder with a plane of symmetry.

   -1 = Plane of symmetry with segments on non-origin side of plane.

   0 = Full cylinder, no plane of symmetry.

   +1 = Plane of symmetry with segments on origin side of plane.

2) MOMOP = Option for generating mother segments and mother-daughter structure data cards.

   0 = No

   1 = Yes

3) KBAR = First boundary number to use

4) MBAR = Number of slices to generate (MBAR+1 parallel planes are generated).

5) LBAR = Number of rings to generate (LBAR or LBAR+1 concentric cylinders are generated).

6) NBAR = Number of wedges to generate (for a full cylinder, NBAR must be an even number. The number of planes generated is NBAR for a half cylinder and NBAR/2 for a full cylinder.

7) JBAR = First segment number to use.

8) MAT = Material number for segments generated.

9-12) Not used

Card #2 (6E12.4)

1) α_p
2) β_p
3) γ_p

Directional cosines of the normal to end planes. If the distance to either end plane is negative, the negative of these cosines is used.

4) α_s
5) β_s
6) γ_s

Directional cosines of the normal to the plane of symmetry.

Card #3 (6E12.4)

1) X_{p1}
2) Y_{p1}
3) Z_{p1}

Coordinates of a point on one of the end planes.

4) X_{p2}
5) Y_{p2}
6) Z_{p2}

Coordinates of a point on the other end plane.

Card #4 (6E12.4)

1) α_c
2) β_c
3) γ_c

Directional cosines of the cylindrical axis.

4) X_c
5) Y_c
6) Z_c

Coordinates of a point on the cylindrical axis.

Card #5 (6E12.4)

1) RC = Radius of outer cylinder.

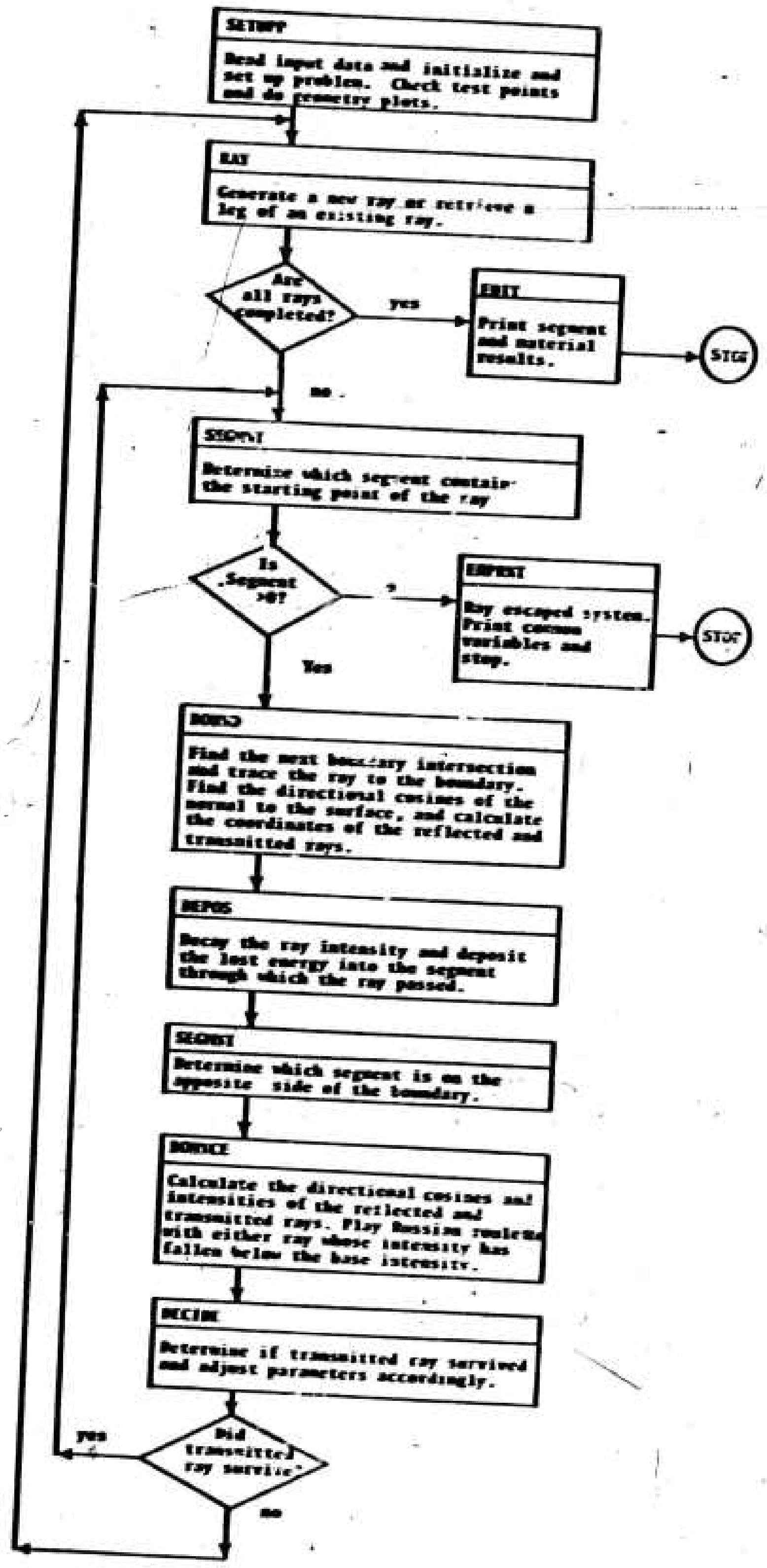
2) RI = Radius of inner cylinder (usually 0.0).

3-6) Not used

APPENDIX C

ZAP FLOW DIAGRAM AND PROGRAM LISTING

ZAP FLOW DIAGRAM



Read input data and initialize and set up problem. Check test points and do geometry plots.

Generate a new ray or retrieve a leg of an existing ray.

Print segment and material results.

Determine which segment contains the starting point of the ray

Ray escaped system. Print common variables and stop.

Find the next boundary intersection and trace the ray to the boundary. Find the directional cosines of the normal to the surface, and calculate the coordinates of the reflected and transmitted rays.

Decay the ray intensity and deposit the lost energy into the segment through which the ray passed.

Determine which segment is on the opposite side of the boundary.

Calculate the directional cosines and intensities of the reflected and transmitted rays. Play Russian roulette with either ray whose intensity has fallen below the base intensity.

Determine if transmitted ray survived and adjust parameters accordingly.

```
      PROGRAM ZAP
C***********************************************************************
C********* ZAP IS THE MAIN PROGRAM AND IS PRIMARILY A CONTROL REGION.
C***********************************************************************
C*********
C********* THE MEANING AND MAXIMUM SIZE OF THE SUBSCRIPTS IS AS FOLLOWS
C*********
C*********  F  WAVELENGTH    200        NOTE THAT F IS INTEGER
C*********  I  STORED RAY     40
C*********  IN INPUT RAY     500
C*********  J  SEGMENT       200
C*********  K  BOUNDARY      200
C*********  KP BOUNDRY PNTR  900
C*********  L  REFLECT TYPE   20
C*********  LM LAMP TYPE      20
C*********  M  MATERIAL       20
C*********  N  SOURCE         50
C*********
C********* THE MEANING OF THE VARIABLES IN COMMON IS AS FOLLOWS
C*********
C********* ABCO(M,F)=ABSORPTION COEFFICIENT OF MATERIAL M AND WAVELENGTH
C********* AL= ALPHA OF RAY BEING FOLLOWED.
C********* ALK(K)= X DIRECTIONAL COSINE ASSOCIATED WITH BOUNDARY K.
C********* ALN=ALPHA OF NORMAL.
C********* ALPHA(I)= X DIRECTIONAL COSINE OF STORED RAY I.
C********* ALR= ALPHA OF REFLECTED RAY.
C********* ALRAY(IN)=ARRAY OF ALPHA FOR INPUT RAYS.
C********* ALRF= ALPHA OF REFRACTED RAY.
C********* BE= BETA  OF RAY BEING FOLLOWED.
C********* BEK(K)= Y DIRECTIONAL COSINE ASSOCIATED WITH BOUNDARY K.
C********* BEN=BETA  OF NORMAL.
C********* BER= BETA  OF REFLECTED RAY.
C********* BERAY(IN)=ARRAY OF BETA FOR INPUT RAYS.
C********* BERF= BETA  OF REFRACTED RAY.
C********* BETA(I) = Y DIRECTIONAL COSINE OF STORED RAY I.
C********* COORDS(IND,N)= SIX COORDINATE LIMITS FOR SOURCE N.
C********* DEV(J)= DEVIATION OR ERROR FOR SEGMENT J.
C********* DIS= DISTANCE FROM POINT TO INTERSECTION.
C********* DK(K)= DISTANCE ASSOCIATED WITH BOUNDARY K.
C********* DMIN= MINIMUM INTERSECTION DISTANCE FOUND.
C********* DZ= DISTANCE BETWEEN TOP AND BOTTOM BOUNDARY.
C********* E(I,F)= ENERGY OF STORED RAY I AT WAVELENGTH F.
C********* EBASE(F)= BASE ENERGY FOR RAY AS A FUNCTION OF WAVELENGTH.
C********* EK(K)= ECCENTRICITY IF BOUNDARY K IS A CONIC.
C********* ELAM(J)= SCALED ENERGY DEPOSITED IN SEGMENT J.
C********* ELAMAT(M)= SCALED ENERGY FOR MATERIAL M.
C********* EMAT(M)= ENERGY DEPOSITED IN MATERIAL M.
C********* ENERGY(J)= SEGMENT ENERGY.
C********* EPS= SMALL DISTANCE FOR MOVING RAY POSITION OFF OF BOUNDARY.
C********* ESOR(LM,F)= RAY ENERGY FOR LAMP TYPE LM AND WAVELENGTH F.
C********* FMAX= NUMBER OF WAVELENGTHS(INTEGER).
C********* GA= GAMMA OF RAY BEING FOLLOWED.
C********* GAK(K)= Z DIRECTIONAL COSINE ASSOCIATED WITH BOUNDARY K.
C********* GAMMA(I)= Z DIRECTIONAL COSINE OF STORED RAY I.
C********* GAN=GAMMA OF NORMAL.
C********* GAR= GAMMA OF REFLECTED RAY.
C********* GARAY(IN)=ARRAY OF GAMMA FOR INPUT RAYS.
C********* GARF= GAMMA OF REFRACTED RAY.
C********* IFLAG(I)= FLAG INDICATING IF STORED RAY I IS LIVE OR DEAD.
C********* IMAX= NUMBER OF RAYS STORED.
```

```
C......... INOW= PRESENT RAY INDEX.
C......... IOPRNT= OPTION FOR PRINTING EACH RAY CREATED.
C......... IPOINT(N)=A POINTER POINTING TO FIRST STORED RAY FOR SOURCE N
C......... IR= LAST RANDOM INTEGER USED.
C......... IRAY= RAY NUMBER BEING TRACED.
C......... ISMAX(N)= NUMBER OF RAYS TO CREATE FOR SOURCE N.
C......... ISOR(LN)= INDEX OF SOURCE TYPE FOR LAMP TYPE LN.
C......... JF(J)= FIRST DAUGHTER OF MOTHER SEGMENT J.
C......... JFL(J)= FLAG INDICATING IF RAY DEPOSITED ENERGY IN SEGMENT J.
C......... JL(J)= LAST DAUGHTER OF MOTHER SEGMENT J.
C......... JM(J)= MOTHER OF DAUGHTER SEGMENT J.
C......... JMAX= MAXIMUM SEGMENT NUMBER.
C......... JN(J)= NEXT SISTER IN HEIRARCHY.
C......... JNOW= SEGMENT RAY IS IN NOW.
C......... JOLD= SEGMENT RAY WAS IN.
C......... JP(J)= PREVIOUS SISTER IN HEIRARCHY.
C......... JRAY(J)= NUMBER OF RAYS WHICH HAVE PASSED THROUGH SEGMENT J.
C......... JSOR(N)= SEGMENT NUMBER OF SOURCE NUMBER N.
C......... KBND(KP)= BOUNDARY NUMBERS FOR SEGMENTS.
C......... KFLAG(K)= FLAG INDICATING IF BOUNDARY K HAS ALREADY BEEN CHEC
C......... KINT= BOUNDARY BEING CONSIDERED FOR INTERSECTION.
C......... KMAX= MAXIMUM BOUNDARY NUMBER.
C......... KNOW= BOUNDARY WHERE RAY INTERSECTED.
C......... KP(J)= INDEX POINTING TO BOUNDARY NUMBERS FOR SEGMENT J.
C......... KTYP(K)= GEOMETRY TYPE FOR BOUNDARY K.
C......... LAMP(N)= LAMP TYPE NUMBER FOR SOURCE NUMBER N.
C......... LANGLE(LN)= INDEX OF ANGLE ROUTINE FOR LAMP TYPE LN.
C......... LREFL(K)= REFLECTION NUMBER FOR BOUNDARY K.
C......... LTYPE(L) = REFLECTION TYPE FOR REFLECTION NUMBER L.
C......... MAT(J)= MATERIAL NUMBER FOR SEGMENT J.
C......... MFL(M)=FLAG INDICATING IF RAY DEPOSITED ENERGY IN MATERIAL M.
C......... MMAX= MAXIMUM MATERIAL NUMBER.
C......... NMAT(M)= NUMBER OF RAYS THAT PASSED THROUGH MATERIAL M.
C......... NNOW= SOURCE NOW BEING USED.
C......... NSOR= MAXIMUM SOURCE NUMBER.
C......... NUMRAY(J)= NUMBER OF RAYS THAT PASSED THROUGH SEGMENT J.
C......... PER= PERCENT OF RAY TRANSMITTED.
C......... RFD(L,F)= REFLECTION DATA FOR REFLECTION L AND WAVELENGTH F.
C......... REF(M)= INDEX OF REFRACTION FOR MATERIAL M.
C......... SIGMAT(M)= TERM NEEDED FOR ERROR ANALYSIS.
C......... SUMRA = SUMMATION OF RAY ENERGY.
C......... SUMRAY(J)= TOTAL ENERGY DEPOSITED IN SEGMENT J BY ONE RAY.
C......... SUMSQR(J)= SUM OF RAY ENERGY SQUARED IN SEGMENT J.
C......... TITLE(12)= VARIABLE ALPHANUMERIC TITLE WHICH DESCRIBES RUN.
C......... VMAT(M)= VOLUME OF MATERIAL M.
C......... VOL(J)= VOLUME OF SEGMENT J.
C......... X(I)= X COORDINATE OF STORED RAY I.
C......... XI= POINT USED FOR FINDING POSITION AND INTERSECTION.
C......... XK(K)= X COORDINATE OF POINT ASSOCIATED WITH BOUNDARY K.
C......... XLAM(F)= ARRAY OF WAVELENGTHS.
C......... XNOW= X OF INTERSECTION POINT.
C......... XOLD= X OF STARTING POINT OF RAY.
C......... XRAY(IN)= X COORDINATES OF INPUT RAYS.
C......... XREF= X OF REFLECTED RAY.
C......... XTRAN= X OF TRANSMITTED RAY.
C......... Y(I)= Y COORDINATE OF STORED RAY I.
C......... YI= POINT USED FOR FINDING POSITION AND INTERSECTION.
C......... YK(K)= Y COORDINATE OF POINT ASSOCIATED WITH BOUNDARY K.
C......... YNOW= Y OF INTERSECTION POINT.
C......... YOLD= Y OF STARTING POINT OF RAY.
C......... YRAY(IN)= Y COORDINATES OF INPUT RAYS.
C......... YREF= Y OF REFLECTED RAY.
```

```
C********* YTRAN= Y OF TRANSMITTED RAY.
C********* Z(I)= Z COORDINATE OF STORED RAY I.
C********* ZI= POINT USED FOR FINDING POSITION AND INTERSECTION.
C********* ZK(K)= Z COORDINATE OF POINT ASSOCIATED WITH BOUNDARY K.
C********* ZLAM(M)= LASER WAVELENGTH OF MATERIAL M.
C********* ZNOW= Z OF INTERSECTION POINT.
C********* ZOLD= Z OF STARTING POINT OF RAY.
C********* ZRAY(IN)= Z COORDINATES OF INPUT RAYS.
C********* ZREF= Z OF REFLECTED RAY.
C********* ZTRAN= Z OF TRANSMITTED RAY.
      COMMON /69/        ABCO(20,200)       ,ALRAY(500)          ,BERAY(500)
     1 ,COORDS(6,50)     ,E(40,200)         ,EBASE(200)          ,ESOR(20,200)
     2 ,GARAY(500)       ,RED(20,200)       ,TITLE(12)           ,VMAT(20)
     3 ,VOL(200)         ,XLAM(200)         ,XRAY(500)           ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/    ALK(200)           ,ALPHA(40)           ,BEK(200)
     1 ,BETA(40)         ,DEV(200)          ,DK(200)             ,EK(200)
     2 ,ELAM(200)        ,ELAMAT(20)        ,EMAT(20)            ,ENERGY(200)
     3 ,GAK(200)         ,GAMMA(40)         ,REF(20)             ,SOMMAT(20)
     4 ,SUMRAY(200)      ,SUMSOR(200)       ,X(40)               ,XK(200)
     5 ,Y(40)            ,YK(200)           ,Z(40)               ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                  IFLAG(40)            ,IPOINT(50)          ,
     ,ISMAX(50)      ,ISOR(20)        ,JF(200)             ,JFL(200)            ,
     ,JL(200)        ,JM(200)         ,JN(200)             ,JP(200)             ,
     ,JRAY(200)      ,JSOR(50)        ,KBAD(900)           ,KFLAG(200)          ,
     ,KP(200)        ,KTYP(200)       ,LAMP(50)            ,LANGLE(20)          ,
     ,LREFL(200)     ,LTYPE(20)       ,MAT(200)            ,MFL(20)             ,
     ,NMAT(20)       ,NUMRAY(200)                                               ,
      COMMON/PARAMS/            AL          ,ALM         ,ALR         ,ALRF        ,BE       ,
     ,BEM        ,BER          ,BERF        ,DIS         ,DMIN        ,DZ          ,EPS      ,
     ,GA         ,GAM          ,GAR         ,GARF        ,PER         ,
     ,SUMRA      ,XI           ,XNOW        ,XOLD        ,XREF        ,XTRAN       ,YI       ,
     ,YNOW       ,YOLD         ,YREF        ,YTRAN       ,ZI          ,
     ,ZNOW       ,ZOLD         ,ZREF        ,ZTRAN
      COMMON/IPARAM/            FMAX        ,IMAX        ,INOW        ,
     ,IOPRAY     ,ICPRNT       ,IR          ,IRAY        ,JMAX        ,JNOW        ,JOLD     ,
     ,KINT       ,KMAX         ,KNOW        ,MMAX        ,MNOW        ,NSOR
      INTEGER F,FMAX
C********* THE LARGE NUMBERED COMMON BLOCK IS FORCED TO LOAD OVER THE
C********* LOADER IN BANK 0. THUS KEEPING THE PROGRAMS IN BANK 1, WHICH
C********* IS FASTER.
      BANK, (0), /69/
C********* BECAUSE THE NUMBERED COMMON BLOCK, UNLIKE OTHER STORAGE, IS
C********* NOT SET TO ZERO ON LOADING, IT MUST BE SEPARATELY ZEROED.
      DIMENSION DUMMY(23932)
      EQUIVALENCE (DUMMY(1),ABCO(1))
      TIME = TIMELEFT(1)
      DO 106 IA=1,23932
      DUMMY(IA) = 0.
  106 CONTINUE
C********* READ INPUT DATA AND SET UP PROBLEM.
      CALL SETUPP
C********* GET THE NEXT RAY TO BE PROCESSED.
  100 CALL RAY(IFLG)
C********* IF THERE ARE NO MORE RAYS GO TO 102.
      IF(IFLG)102,103,103
C********* DETERMINE WHICH SEGMENT CONTAINS STARTING POINT OF RAY.
  103 CALL SEGMNT
C********* IF SEGMENT NUMBER IS ZERO THE RAY IS OUTSIDE THE SYSTEM.
      IF(JNOW)104,104,101
C********* FIND POINT WHERE RAY INTERSECTS THE NEAREST BOUNDARY.
```

```
   101 CALL BOUND
C.......... DEPOSIT ENERGY IN SEGMENT RAY HAS JUST CROSSED.
       CALL DEPOS
C.......... DETERMINE WHICH SEGMENT CONTAINS TRANSMITTED RAY.
       CALL SEGMNT
C.......... GET DIRECTIONAL COSINES AND ENERGY OF REFLECTED AND
C.......... TRANSMITTED RAYS. PLAY RUSSIAN ROULET IF EITHER RAYS
C.......... ENERGY LEVEL IS BELOW CHOSEN VALUE.
   105 CALL BOUNCE
C.......... DETERMINE IF NEW RAY IS NEEDED.
       CALL DECIDE(IFLG)
       IF(IFLG)101,101,100
   102 CONTINUE
C.......... PRINT FINAL(OR SEMI-FINAL) ANSWERS.
       CALL EDIT
       TIME = TIME - TIMELEFT(1)
       PRINT 10, TIME
    10 FORMAT(1H ,17HEXECUTION TIME = ,F8.3,8H SECONDS)
       STOP
C.......... ERROR CONDITION. RAY HAS ESCAPED SYSTEM.
   104 CALL ERPRNT(6H   ZAP)
       STOP
       END
```

```
      SUBROUTINE ANGLES(TH,PHI)
C*******************************************************************
C********** SUBROUTINE ANGLES CALLS THE DESIRED ANGLE ROUTINE.*******
C*******************************************************************
      COMMON /69/                ABCO(20,200)     ,ALRAY(500)      ,BERAT(500)
     1 ,COORDS(6,50)   ,E(40,200)        ,EBASE(200)      ,ESOR(20,200)
     2 ,GARAY(500)     ,RED(20,200)      ,TITLE(12)       ,VMAT(20)
     3 ,VOL(200)       ,XLAM(200)        ,XRAY(500)       ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/  ALK(200)          ,ALPHA(40)       ,BEK(200)
     1 ,BETA(40)       ,DEV(200)         ,DK(200)         ,EK(200)
     2 ,ELAM(200)      ,ELAMAT(20)       ,EMAT(20)        ,ENERGY(200)
     3 ,GAK(200)       ,GAMMA(40)        ,REF(20)         ,SORMAT(20)
     4 ,SUMRAY(200)    ,SUMSOR(200)      ,X(40)           ,XK(200)
     5 ,Y(40)          ,YK(200)          ,Z(40)           ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                 IFLAG(40)       ,IPOINT(50)      ,
     ,ISMAX(50)     ,ISOR(20)        ,JF(200)         ,JFL(200)        ,
     ,JL(200)       ,JM(200)         ,JN(200)         ,JP(200)         ,
     ,JRAY(200)     ,JSOR(50)        ,KBND(900)       ,KFLAG(200)      ,
     ,KP(200)       ,KTYP(200)       ,LAMP(50)        ,LANGLE(20)      ,
     ,LREFL(200)    ,LTYPE(20)       ,MAT(200)        ,MFL(20)         ,
     ,NMAT(20)      ,NUMRAY(200)
      COMMON/PARAMS/           AL       ,ALM      ,ALR      ,ALRF
     ,BEN      ,BER       ,BERF     ,DIS      ,DMIN     ,DZ       ,BE     ,
     ,GA       ,GAM       ,GAR      ,GARF     ,PER                ,EPS    ,
     ,SUMRA    ,XI        ,XNOW     ,XOLD     ,XREF     ,
     ,YNOW     ,YOLD      ,YREF     ,YTRAN    ,ZI       ,XTRAN    ,YI     ,
     ,ZNOW     ,ZOLD      ,ZREF     ,ZTRAN              ,
      COMMON/IPARAM/           FMAX     ,IMAX     ,INOW     ,
     ,IOFRAY   ,IOPRNT    ,IR       ,IRAY     ,JMAX     ,JNOW     ,JOLD   ,
     ,KINT     ,KMAX      ,KNOW     ,NMAX     ,NNOW     ,NSOR
      INTEGER F,FMAX
C********** GET LAMP NUMBER FOR SOURCE NNOW.
      LT=LAMP(NNOW)
C********** GET NUMBER OF ROUTINE TO CALL.
      LA=LANGLE(LT)
C********** GO TO DESIRED CALL.
      GO TO (100,200,300,400,500,600,700,800,900),LA
  100 CALL ANGLE1(TH,PHI)
      GO TO 110
  200 CALL ANGLE2(TH,PHI)
      GO TO 110
  300 CALL ANGLE3(TH,PHI)
      GO TO 110
  400 CALL ANGLE4(TH,PHI)
      GO TO 110
  500 CALL ANGLE5(TH,PHI)
      GO TO 110
  600 CALL ANGLE6(TH,PHI)
      GO TO 110
  700 CALL ANGLE7(TH,PHI)
      GO TO 110
  800 CALL ANGLE8(TH,PHI)
      GO TO 110
  900 CALL ANGLE9(TH,PHI)
  110 RETURN
      END
      SUBROUTINE ABSORP(IAB,M)
C*************************************************************************
C********** SUBROUTINE ABSORP CALLS THE DESIRED ROUTINE FOR GENERATING
C********** ABSORPTION COEFFICIENTS AS A FUNCTION OF WAVELENGTH.
C*************************************************************************
      COMMON /69/         ABCO(20,200)      ,ALRAY(500)        ,BERAY(500)
     1 ,COORDS(6,55)    ,E(40,200)        ,EBASE(200)        ,ESOR(20,200)
     2 ,GARAY(500)      ,RED(20,200)      ,TITLE(12)         ,VMAT(20)
     3 ,VOL(200)        ,XLAM(200)        ,XRAY(500)         ,TRAY(500)
     4 ,ZRAT(500)
      COMMON /ARRAYS/   ALK(200)          ,ALPHA(40)         ,BEK(200)
     1 ,BETA(40)        ,DEV(200)         ,DK(200)           ,EK(200)
     2 ,ELAM(200)       ,ELAMAT(20)       ,EMAT(20)          ,ENERGT(200)
     3 ,GAK(200)        ,GAMMA(40)        ,REF(20)           ,SORMAT(20)
     4 ,SUMRAY(200)     ,SUMSOR(200)      ,X(40)             ,XK(200)
     5 ,Y(40)           ,YK(200)          ,Z(40)             ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                  IFLAG(40)         ,IPOINT(50)      ,
     ,ISMAX(50)       ,ISOR(20)       ,JF(200)          ,JFL(200)        ,
     ,JL(200)         ,JM(200)        ,JN(200)          ,JP(200)         ,
     ,JRAY(200)       ,JSOR(50)       ,KBAD(900)        ,KFLAG(200)      ,
     ,KP(200)         ,KTYP(200)      ,LAMP(50)         ,LANGLE(20)      ,
     ,LREFL(200)      ,LTYPE(20)      ,MAT(200)         ,MFL(20)         ,
     ,NMAT(20)        ,NUMRAY(200)
      COMMON/PARAMS/            AL         ,ALN        ,ALR        ,ALRF       ,RE      ,
     ,BEN        ,BER        ,BERF       ,DIS        ,DMIN       ,DZ         ,EPS     ,
     ,GA         ,GAN        ,GAR        ,GARF       ,PER        ,
     ,SUMRA      ,XI         ,XNOW       ,XOLD       ,XREF       ,XTRAN      ,YI      ,
     ,YNOW       ,YOLD       ,TREF       ,TTRAN      ,ZI         ,
     ,ZNOW       ,ZOLD       ,ZREF       ,ZTRAN
      COMMON/IPARAM/            FMAX       ,IMAX       ,INOW       ,
     ,IOPRAY     ,IOPRNT     ,IR         ,IRAY       ,JMAX       ,JNOW       ,JOLD    ,
     ,KINT       ,KMAX       ,KNOW       ,NMAX       ,NNOW       ,NSOR
      INTEGER F,FMAX
      DIMENSION TSTG(200)
      DIMENSION IABTAB(9).
      DATA(IABTAB=6HABS1   ,6HABS2   ,6HABS3   ,
     ,6HABS4   ,6HABS5   ,6HABS6   ,6HABS7   ,6HABS8   ,6HABS9   )
C********** FIND NUMBER OF ROUTINE TO CALL.
      DO 101 N=1,9
      IF(IAB-IABTAB(N))101,102,101
  101 CONTINUE
C********** ROUTINE NAME NOT IN TABLE.
      PRINT 10,IAB
   10 FORMAT(1H1,21HABSORPTION SUBROUTINE,1X,A6,13H NOT IN TABLE)
      STOP
C********** GO TO DESIRED CALL
  102 GO TO(100,200,300,400,500,600,700,800,900),N
  100 CALL ABS1(XLAM,FMAX,TSTG       ,M)
      GO TO 110
  200 CALL ABS2(XLAM,FMAX,TSTG       ,M)
      GO TO 110
  300 CALL ABS3(XLAM,FMAX,TSTG       ,M)
      GO TO 110
  400 CALL ABS4(XLAM,FMAX,TSTG       ,M)
      GO TO 110
  500 CALL ABS5(XLAM,FMAX,TSTG       ,M)
      GO TO 110
  600 CALL ABS6(XLAM,FMAX,TSTG       ,M)
      GO TO 110
  700 CALL ABS7(XLAM,FMAX,TSTG       ,M)
      GO TO 110
  800 CALL ABS8(XLAM,FMAX,TSTG       ,M)
      GO TO 110
  900 CALL ABS9(XLAM,FMAX,TSTG       ,M)
  110 CONTINUE
C********** STORE ABSORPTION COEFFICIENTS FOR MATERIAL NO. M.
      DO 103 F=1,FMAX
      ABCO(M,F)=TSTG(F)
  103 CONTINUE
      RETURN
      END
      SUBROUTINE BCALC
C*************************************************************************
C********** BCALC CALCULATES FUNCTION B(TH), DERIVATIVE BP(TH), AND
C********** DISTANCE STH(TH).
C********** PART OF HELIX INTERSECTION CALCULATION.
C*************************************************************************
      COMMON /69/        ABCO(20,200)       ,ALRAY(500)         ,BERAY(500)
     1 ,COORDS(6,50)   ,E(40,200)         ,EBASE(200)         ,ESOM(20,200)
     2 ,GARAY(500)     ,RED(20,200)       ,TITLE(12)          ,VMAT(20)
     3 ,VOL(200)       ,XLAM(200)         ,XRAY(500)          ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/   ALK(200)          ,ALPHA(40)          ,BEK(200)
     1 ,BETA(40)       ,DEV(200)          ,DK(200)            ,EK(200)
     2 ,ELAM(200)      ,ELAMAT(20)        ,EMAT(20)           ,ENERGY(200)
     3 ,GAK(200)       ,GAMMA(40)         ,REF(20)            ,SORMAT(20)
     4 ,SUMRAY(200)    ,SUMSOR(200)       ,X(40)              ,XK(200)
     5 ,Y(40)          ,YK(200)           ,Z(40)              ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                    IFLAG(40)       ,IPOINT(50)      ,
     *,ISMAX(50)     ,ISOR(20)          ,JF(200)        ,JFL(200)        ,
     *,JL(200)       ,JM(200)           ,JN(200)        ,JP(200)         ,
     *,JRAY(200)     ,JSOR(50)          ,KBND(900)      ,KFLAG(200)      ,
     *,KP(200)       ,KTYP(200)         ,LAMP(50)       ,LANGLE(20)      ,
     *,LREFL(200)    ,LTYPE(20)         ,MAT(200)       ,MFL(20)         ,
     *,MMAT(20)      ,NUMRAY(200)
      COMMON/PARAMS/          AL        ,ALM        ,ALR        ,ALMF        ,BE       ,
     *,BEM        ,BER        ,BERF       ,DIS        ,DMIN       ,DZ          ,EPS      ,
     *,GA         ,GAM        ,GAR        ,GARF       ,PER        ,
     *,SUMRA      ,XI         ,XNOW       ,XOLD       ,XREF       ,XTRAN       ,YI       ,
     *,YNOW       ,YOLD       ,YREF       ,YTRAN      ,ZI         ,
     *,ZNOW       ,ZOLD       ,ZREF       ,ZTRAN
      COMMON/IPARAM/          FMAX      ,IMAX       ,INOW       ,
     *,IOPRAY     ,IOPRNT     ,IR         ,IRAY       ,JMAX       ,JNOW        ,JOLD     ,
     *,KINT       ,KMAX       ,KNOW       ,MMAX       ,NNOW       ,NSOR
      INTEGER F,FMAX
      COMMON/HELCOM/A,ABAR,B,BI,BIP,BP,CAP,DELTH,DELX,DELY,DELZ,DMIT,
     *PSIZ,REV,RHO,STH,TH,THI,SORKS,RKS,CSTH,SNTH,RCSTH,RSNTH,BSTH,
     *COSTAN,THZ,DTHZ
C********** CALCULATE PARAMETERS.
      STH=SIN(TH)
      CTH=COS(TH)
      RCOS=RHO*CTH
      RSIN=RHO*STH
      DEN=-AL*RSIN+BE*RCOS+GA*CAP
      ENUM=-DELX*RSIN+DELY*RCOS+(DELZ+CAP*TH)*CAP
C********** CALCULATE DISTANCE STH.
      STH=ENUM/DEN
C********** CALCULATE DERIVATIVE OF STH.
      SP=((-DELX*RCOS-DELY*RSIN+CAP**2)*DEN-ENUM*(-AL*RCOS-BE*RSIN))
      SP=SP/(DEN**2)
      ALP=DELX+RCOS-AL*STH
      BEB=DELY+RSIN-BE*STH
      GAR=DELZ+CAP*TH-GA*STH
C********** CALCULATE FUNCTION B.
      B=.5*ALB**2+.5*BEB**2+.5*GAB**2
C********** CALCULATE DERIVATIVE OF B.
      BP=ALB*(-RSIN-AL*SP)+BEB*(RCOS-BE*SP)+GAB*(CAP-GA*SP)
      RETURN
      END
      SUBROUTINE BNDDAT
C***********************************************************************
C********* SUBROUTINE BNDDAT READS BOUNDARY DATA AND SETS UP BOUNDARIES.
C***********************************************************************
      COMMON /69/        ABCO(20,200)      ,ALRAY(500)       ,BERAY(500)
     1 ,COORDS(6,50)   ,E(40,200)         ,EBASE(200)       ,ESOR(20,200)
     2 ,GARAY(500)     ,RED(20,200)       ,TITLE(12)        ,VMAT(20)
     3 ,VOL(200)       ,XLAM(200)         ,XRAY(500)        ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/    ALK(200)          ,ALPHA(40)        ,BEK(200)
     1 ,BETA(40)       ,DEV(200)          ,DK(200)          ,EK(200)
     2 ,ELAM(200)      ,ELAMAT(20)        ,EMAT(20)         ,ENERGY(200)
     3 ,GAK(200)       ,GAMMA(40)         ,REF(20)          ,SGMAT(20)
     4 ,SUMRAY(200)    ,SUMSOR(200)       ,X(40)            ,XK(200)
     5 ,Y(40)          ,YK(200)           ,Z(40)            ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                      IFLAG(40)        ,IPOINT(50)      ,
     *,ISMAX(50)     ,ISOR(20)          ,JF(200)          ,JFL(200)        ,
     *,JL(200)       ,JM(200)           ,JN(200)          ,JP(200)         ,
     *,JMAT(200)     ,JSOR(50)          ,KBND(900)        ,KFLAG(200)      ,
     *,KP(200)       ,KTYP(200)         ,LAMP(50)         ,LANGLE(20)      ,
     *,LREFL(200)    ,LTYPE(20)         ,MAT(200)         ,MFL(20)         ,
     *,MMAT(20)      ,NUMRAY(200)
      COMMON/PARAMS/          AL         ,ALN       ,ALR       ,ALRF      ,BE    ,
     *,BEN       ,BER       ,BERF       ,DIS       ,DMIN      ,DZ        ,EPS   ,
     *,GA        ,GAN       ,GAR        ,GANF      ,PER       ,
     *,SUMMA     ,XI        ,XNOW       ,XOLD      ,XREF      ,XTRAN     ,YI    ,
     *,YNOW      ,YOLD      ,YREF       ,YTRAN     ,ZI        ,
     *,ZNOW      ,ZOLD      ,ZREF       ,ZTRAN
      COMMON/IPARAM/          FMAX       ,IMAX      ,INOW      ,
     *,IOPRAY    ,IOPRNT    ,IR         ,IRAY      ,JMAX      ,JNOW      ,JOLD  ,
     *,KINT      ,KMAX      ,KNOW       ,MMAX      ,NNOW      ,NSOR
      INTEGER F,FMAX
      COMMON/BNDCOM/BNDPAR(12)
      DIMENSION KTABLE(10)
      DATA(KTABLE=6HPLANE ,6HCYLIND,6HCONIC ,6HSPHERE,6HCONE  ,6HPARAB ,
     *6HHYPERB,6HELLIPS,6HHELIX ,6H      )
      PRINT 12
   12 FORMAT(1H1,53X,13HBOUNDARY DATA//6H BOUND,2X,4HREFL,3X,
     *5HBOUND,3X,5HALPHA,4X,4HBETA,3X,5HGAMMA,7X,1HX,7X,1HY,
     *7X,1HZ,6X,2HX2,6X,2HY2,6X,2HX3,6X,2HY3,5X,3HDIS,5X,3HECC/
     *6H  NUMB,2X,4HNUMB,4X,4HTYPE/)
      NLP=5
      KMAX=0
C********** LOOP THROUGH ALL BOUNDARIES.
  104 READ 10,K,LREFI,KTYPI,(BNDPAR(N),N=1,8)
   10 FORMAT(2I4,1X,A6,8F7.5)
C********** IF K GREATER THAN KMAX, KMAX=K.
      IF(K)111,111,105
  105 IF(K-KMAX)106,106,107
  107 KMAX=K
C********** DETERMINE GEOMETRY TYPE
  106 DO 108 KT=1,10
      KTYP(K)=KT
      IF(KTYPI-KTABLE(KT))108,109,108
  108 CONTINUE
C********** GEOMETRY TYPE NOT IN KTABLE.
      CALL ERPRNT(6HBNDDAT)
C********** STORE REFLECTION NUMBER.
  109 LREFL(K)=LREFI
      KTYPI=KTYP(K)
```

```
C.......... BRANCH ON GEOMETRY TYPE.
  102 GO TO(100,200,300,400,500,600,700,800,900,1000),NTYPI
C.......... GENERATE A PLANE.
  100 CALL SETPLA(K)
      GO TO 110
C.......... GENERATE A CYLINDER.
  200 CALL SETCYL(K)
      GO TO 110
C.......... GENERATE A CONIC.
  300 CALL SETCON(K)
      GO TO 110
C.......... GENERATE A SPHERE
  400 CALL SETSPH(K)
      GO TO 110
C.......... GENERATE A HALF-CONE
  500 CALL SETCN(K)
      GO TO 110
C.......... GENERATE A PARABOLOID
  600 CALL SETPAR(K)
      GO TO 110
C.......... GENERATE A HYPERBOLOID
  700 CALL SETHYP(K)
      GO TO 110
C.......... GENERATE AN ELLIPSOID
  800 CALL SETELL(K)
      GO TO 110
C.......... GENERATE A HELIX
  900 CALL SETHEL(K)
      GO TO 110
 1000 CONTINUE
      GO TO 110
  110 NLP=NLP+1
C.......... IF NUMBER OF LINES PRINTED EXCEEDS 52, EJECT AND PRINT TITLE.
      IF(NLP-52)104,104,112
  112 NLP=5
      PRINT 12
C.......... GO READ NEXT BOUNDARY CARD.
      GO TO 104
  111 RETURN
      END
      SUBROUTINE BOUNCE
C**********************************************************************
C********** BOUNCE DETERMINES THE DIRECTIONAL COSINES AND ENERGY OF
C********** THE TRANSMITTED AND REFLECTED RAYS AND DETERMINES IF THEY
C********** SURVIVE.
C**********************************************************************
      COMMON /69/          ABCO(20,200)       ,ALRAY(500)        ,BERAY(500)
     1 ,COCHES(6,50)      ,E(40,200)         ,EBASE(200)        ,ESOR(20,200)
     2 ,GARAY(500)        ,RED(20,200)       ,TITLE(12)         ,VMAT(20)
     3 ,VOL(200)          ,XLAM(200)         ,XRAY(500)         ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/      ALK(200)           ,ALPHA(40)         ,BEK(200)
     1 ,BETA(40)          ,DEV(200)          ,DK(200)           ,EK(200)
     2 ,ELAM(200)         ,ELAMAT(20)        ,EMAT(20)          ,ENERGY(200)
     3 ,GAK(200)          ,GAMMA(40)         ,REF(20)           ,SCRMAT(20)
     4 ,SUMRAY(200)       ,SUMSOR(200)       ,X(40)             ,XK(200)
     5 ,Y(40)             ,YK(200)           ,Z(40)             ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                      IFLAG(40)         ,IPOINT(50)        ,
     *ISMAX(50)       ,ISOR(20)           ,JF(200)          ,JFL(200)          ,
     *JL(200)         ,JM(200)            ,JN(200)          ,JP(200)           ,
     *JRAY(200)       ,JSCR(50)           ,KBND(900)        ,KFLAG(200)        ,
     *KP(200)         ,KTYP(200)          ,LAMP(50)         ,LANGLE(20)        ,
     *LREFL(200)      ,LTYPE(20)          ,MAT(200)         ,MFL(20)           ,
     *MMAT(20)        ,NUMRAY(200)
      COMMON/PARAMS/          AL            ,ALN          ,ALR          ,ALRF         ,BE      ,
     *BEK         ,BER          ,BERF          ,DIS          ,DMIN         ,DZ           ,EPS     ,
     *GA          ,GAN          ,GAR           ,GARF         ,PER          ,
     *SUMRA       ,XI           ,XNOW          ,XOLD         ,XREF         ,XTRAN        ,YI      ,
     *YNOW        ,YOLD         ,YREF          ,YTRAN        ,ZI           ,
     *ZNOW        ,ZOLD         ,ZREF          ,ZTRAN
      COMMON/IPARAM/          FMAX          ,IMAX         ,INOW         ,
     *IOPRAY      ,IOPRNT       ,IR            ,IRAY         ,JMAX         ,JNOW         ,JOLD    ,
     *KINT        ,KMAX         ,KNOW          ,NMAX         ,NNOW         ,NSOR
      INTEGER F,F  AX
      I=INOW
      K=KNOW
C********** SET COORDINATES OF TRANSMITTED RAY.
      X(I)=XTRAN
      Z(I)=ZTRAN
      Y(I)=YTRAN
C********** IF RAY ENERGY LESS THAN .001*(BASE ENERGY), SKIP CALCULATIONS
      IEFLAG=0
      DO 114 F=1,FMAX
      IF(E(I,F)-(1.E-3)*EBASE(F))115,115,116
  115 E(I,F)=0.0
      GO TO 114
  116 IEFLAG=1
  114 CONTINUE
      IF(IEFLAG)120,120,102
C********** IF DUMMY BOUNDARY, GO TO 103.
  102 IF(LREFL(K)-1)109,103,109
C********** IF TOP CONTINUATIVE BOUNDARY, GO TO 103.
  109 IF(LREFL(K)-4)110,103,110
C********** IF BOTTOM CONTINUATIVE BOUNDARY, GO TO 103.
  110 IF(LREFL(K)-5)104,103,104
C********** PLAY RUSSIAN ROULET WITH TRANSMITTED RAY.
  103 CALL ROULET(1)
      GO TO 120
  104 M1=MAT(JOLD)
      M2=MAT(JNOW)
```

```
C.......... IF REFRACTIVE INDICES ARE EQUAL. TREAT AS DUMMY BOUNDARY.
       IF(ABS(REF(M1)-REF(M2))-1.E-[illegible])103.103.130
C.......... CALCULATE DIRECTIONAL COSINES OF REFLECTED RAY.
  130 CALL REFLCT
C.......... STORE REFLECTED RAY ON INDEX IMAX.
      IMAX=IMAX+1
      ALPHA(IMAX)=ALR
      BETA(IMAX)=BER
      GAMMA(IMAX)=GAR
      X(IMAX)=XREF
      Y(IMAX)=YREF
      Z(IMAX)=ZREF
C.......... IF BOUNDARY OF TOTAL REFLECTION. GO TO 105.
      IF(LREFL(K)-2)106.105.106
C.......... REFLECT TOTAL RAY.
  105 DO 111 F=1.FMAX
      E(IMAX.F)=E(I.F)
      E(I.F)=0.0
  111 CONTINUE
C.......... PLAY RUSSIAN ROULET WITH REFLECTED RAY.
      CALL ROULET(IMAX)
      GO TO 120
C.......... CALCULATE DIRECTIONAL COSINES OF TRANSMITTED RAY AND PERCENT
C.......... OF RAY TO BE TRANSMITTED.
  106 CALL REFRAC
C.......... PLAY RUSSIAN ROULET WITH TRANSMITTED RAY.
      CALL ROULET(I)
C.......... PLAY RUSSIAN ROULET WITH REFLECTED RAY.
  100 CALL ROULET(IMAX)
  120 CALL DEBUG(6HBOUNCE)
C.......... SET FLAG INDICATING RAY EXISTS
      IFLAG(IMAX)=1
      IFLAG(I)=1
      RETURN
      END
```

```
FTN5.5A
                                                                        05/26/71
          SUBROUTINE BOUND
C***********************************************************************  BOUND
C********** BOUND DETERMINES POINT WHERE RAY INTERSECTS NEAREST BOUNDARY.BOUND
C************************************************************************
      COMMON /69/          ABCO(20,200)      ,ALRAY(500)       ,BERAY(500)
     1 ,COORDS(6,500)     ,E(40,200)        ,EBASE(200)       ,ESOR(20,200)
     2 ,GARAY(500)        ,RED(20,200)      ,TITLE(12)        ,VMAT(20)
     3 ,VOL(200)          ,XLAM(200)        ,XRAY(500)        ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/      ALK(200)
     1 ,BETA(40)          ,DEV(200)         ,ALPHA(40)        ,BEK(200)
     2 ,ELAM(200)         ,ELAMAT(20)       ,DK(200)          ,EK(200)
     3 ,GAK(200)          ,GAMMA(40)        ,EMAT(20)         ,ENERGY(200)
     4 ,SUMRAY(200)       ,SUMSCR(200)      ,REF(20)          ,SCRMAT(20)
     5 ,Y(40)             ,YK(200)          ,X(40)            ,XK(200)
     6 ,ZLAM(20)                            ,Z(40)            ,ZK(200)
      COMMON/IARRAY/                  IFLAG(40)
     ,ISMAX(50)       ,ISOR(20)       ,JF(200)        ,IPOINT(50)      ,
     ,JL(200)         ,JM(200)        ,JN(200)        ,JFL(200)        ,
     ,JRAY(200)       ,JSOR(50)       ,KBND(900)      ,JP(200)         ,
     ,KP(200)         ,KTYP(200)      ,LAMP(50)       ,KFLAG(200)      ,
     ,LREFL(200)      ,LTYPE(20)      ,MAT(200)       ,LANGLE(20)      ,
     ,MMAT(20)        ,NUMRAY(200)                    ,NFL(20)         ,
      COMMON/PARAMS/           AL
     ,BEN        ,BER        ,BERF       ,ALN        ,ALR        ,ALRF       ,BE      ,
     ,GA         ,EAN        ,GAR        ,DIS        ,DMIN       ,DZ         ,EPS     ,
     ,SUMRA      ,XI         ,XNOW       ,GARF       ,PEM        ,
     ,YNOW       ,YOLD       ,YREF       ,XOLD       ,XREF       ,XTRAN      ,YI      ,
     ,ZNOW       ,ZOLD       ,ZREF       ,YTRAN      ,ZI         ,
      COMMON/IPARIN/           FMAX       ,ZTRAN
     ,IOPRAY     ,IOPRNT     ,IR         ,IMAX       ,INOW       ,
     ,KINT       ,KMAX       ,KNOW       ,IRAY       ,JMAX       ,JNOW       ,JOLD    ,
      INTEGER F,FMAX                     ,MMAX       ,MNOW       ,KSOR
      DMIN=1.E+70
C********** CHECK BOUNDARIES OF SEGMENT CONTAINING STARTING POINT OF RAY. BOUND
  101 J=JNOW                                                              BOUND
  102 CALL JBOUND(J)                                                      BOUND
C********** IF DISTANCE LESS THAN MINIMUM, SET MINIMUM EQUAL TO DISTANCE.BOUND
      IF(DIS-DMIN)105,130,104                                             BOUND
C********** IF DISTANCE EQUAL MINIMUM AND J=JNOW, CHOOSE NEW BOUNDARY.    BOUND
  130 IF(J-JNOW)104,105,104                                               BOUND
  105 KNOW=KINT                                                           BOUND
      DMIN=DIS                                                            BOUND
C********** IF JNOW IS A MOTHER,GO TO 106.                                BOUND
  104 IF(JF(JNOW))106,110,106                                             BOUND
C********** SET J EQUAL TO FIRST DAUGHTER.                                BOUND
  106 J=JF(JNOW)                                                          BOUND
      GO TO 107                                                           BOUND
C********** ARE THERE MORE SEGMENT TO CHECK. IF NOT GO TO 110.            BOUND
  112 IF(JN(J))109,110,109                                                BOUND
C********** CHECK NEXT SEGMENT IN HEIRARCHY.                              BOUND
  109 J=JN(J)                                                             BOUND
  107 CALL JBOUND(J)                                                      BOUND
C********** IF DIS LESS THAN DMIN, SAVE NEW BOUNDARY.                     BOUND
      IF(DIS-DMIN)111,131,112                                             BOUND
C********** IF DIS EQUAL DMIN AND J=JNOW, SAVE NEW BOUNDARY.               BOUND
                                                                          BOUND
  131 IF(J-JNOW)112,111,112
  111 KNOW=KINT                                                              BOUND
      DMIN=DIS                                                               BOUND
      GO TO 112                                                              BOUND
C********** IF NO INTERSECTION WAS FOUND, THERE IS AN ERROR.                 BOUND
  110 IF(DMIN-1.E+20)113,114,114                                             BOUND
  114 CALL ERPRNT(6HBOUND )                                                  BOUND
C********** SET POINT OF INTERSECTION AND STARTING POINT FOR                  BOUND
C********** TRANSMITTED AND REFLECTED RAYS.                                   BOUND
  113 XNOW=XI+DMIN*AL                                                        BOUND
      YNOW=YI+DMIN*BE                                                        BOUND
      ZNOW=ZI+DMIN*GA                                                        BOUND
C********** CALCULATE NORMAL TO POINT OF INTERSECTION.                        BOUND
      CALL NORMAL                                                            BOUND
      ANG=AL*ALN+BE*BEN+GA*GAN
      SN=SIGN(EPS,ANG)                                                       BOUND
C********** SET COORDINATES OF TRANSMITTED RAY.                               BOUND
      XTRAN=XNOW+SN*ALN                                                      BOUND
      YTRAN=YNOW+SN*BEN                                                      BOUND
      ZTRAN=ZNOW+SN*GAN                                                      BOUND
C********** SET COORDINATES OF REFLECTED RAY.                                 BOUND
      XREF=XNOW-SN*ALN                                                       BOUND
      YREF=YNOW-SN*BEN                                                       BOUND
      ZREF=ZNOW-SN*GAN                                                       BOUND
C********** IF POINT IS ON BOUNDARY OF CONTINUITY, ADJUST Z COORDINATE       BOUND
C********** OF TRANSMITTED RAY.                                               BOUND
      IF(LREFL(KNOW)-4)123,122,123                                           BOUND
  122 SGN=-1.0                                                               BOUND
      GO TO 125                                                              BOUND
  123 IF(LREFL(KNOW)-5)126,124,126                                           BOUND
  124 SGN=1.0                                                                BOUND
  125 ZTRAN=ZTRAN+SIGN(DZ,SGN)                                               BOUND
      Z(INOW)=Z(INOW)+SIGN(DZ,SGN)                                           BOUND
C********** SET COORDINATES OF PRESENT RAY EQUAL TO TRANSMITTED RAY.          BOUND
  126 XI=XTRAN                                                               BOUND
      YI=YTRAN                                                               BOUND
      ZI=ZTRAN                                                               BOUND
  120 CONTINUE                                                               BOUND
      CALL DEBUG(6H BOUND)                                                   BOUND
      RETURN                                                                 BOUND
      END                                                                    BOUND
                                                                             BOUND
```

```
                                  SUBROUTINE COSTAN
C**********************************************************************************
C********* COSTAN CALCULATES COSTAN.
C********* PART OF HELIX INTERSECTION CALCULATION.
C**********************************************************************************
      COMMON /69/          ABCO(20,200)        ,ALRAY(500)        ,BERAY(500)
     1 ,COORDS(6,50)      ,E(40,200)           ,EBASE(200)        ,ESOR(20,200)
     2 ,GARAY(500)        ,RED(20,200)         ,TITLE(12)         ,VMAT(20)
     3 ,VOL(200)          ,XLAM(200)           ,XRAY(500)         ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/      ALK(200)            ,ALPHA(40)         ,BEK(200)
     1 ,BETA(40)          ,DEV(200)            ,CK(200)           ,EK(200)
     2 ,ELAM(200)         ,ELAMAT(20)          ,EMAT(20)          ,ENERGY(200)
     3 ,GAK(200)          ,GAMMA(40)           ,REF(20)           ,SUMMAT(20)
     4 ,SUMRAY(200)       ,SUMSUR(200)         ,X(40)             ,XK(200)
     5 ,Y(40)             ,YK(200)             ,Z(40)             ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                   IFLAG(40)          ,IPOINT(50)       ,
     ,ISMAX(50)        ,ISOR(20)         ,JF(200)           ,JFL(200)         ,
     ,JL(200)          ,JM(200)          ,JN(200)           ,JP(200)          ,
     ,JRAY(200)        ,JSOR(50)         ,KBND(900)         ,KFLAG(200)       ,
     ,KP(200)          ,KTYP(200)        ,LAMP(50)          ,LANGLE(20)       ,
     ,LREFL(200)       ,LTYPE(20)        ,MAT(200)          ,MFL(20)          ,
     ,MMAT(20)         ,NUMRAY(200)
      COMMON/PARAMS/           AL           ,ALN          ,ALR          ,ALRF         ,BE     ,
     ,BEN          ,BER          ,BERF         ,DIS          ,DMIN         ,DZ           ,EPS    ,
     ,GA           ,GAN          ,GAR          ,GARF         ,PER          ,
     ,SUMRA        ,XI           ,XNOW         ,XOLD         ,XREF         ,XTRAN        ,YI     ,
     ,YNOW         ,YOLD         ,YREF         ,YTRAN        ,ZI           ,
     ,ZNOW         ,ZOLD         ,ZREF         ,ZTRAN
      COMMON/IPARAM/           FMAX         ,IMAX         ,INOW         ,
     ,IOPRAY       ,IOPRNT       ,IR           ,IRAY         ,JMAX         ,JNOW         ,JOLD   ,
     ,KINT         ,KMAX         ,KNOW         ,MMAX         ,MNOW         ,NSOR
      INTEGER F,FMAX
      COMMON/HELCOM/A,ABAR,B,B1,BIP,BP,CAP,DELTH,DELX,DELY,DELZ,DMIT,
     ,PSIZ,REV,RHO,STH,TH,TH1,SQRKS,RKS,CSTH,SNTH,RCSTH,RSNTH,BSTH,
     ,COSTAN,THZ,DTHZ
      CSTH=COS(TH)
      SNTH=SIN(TH)
      RCSTH=RHO*CSTH
      RSNTH=RHO*SNTH
      COSTAN=(-RSNTH*AL+RCSTH*BE+CAP*GA)/SQRKS
      RETURN
      END
      SUBROUTINE CHECK(REG,AA,BB,GG)
C***********************************************************************
C********** SUBROUTINE CHECK ASSURES THAT THE SUM OF THE SQUARES OF A
C********** SET OF DIRECTIONAL COSINES ADDS UP TO ONE.
C***********************************************************************
      ONE=AA**2+BB**2+GG**2
C********** IF THE SUM OF THE SQUARES IS LESS THAN 1.E-3, GO TO 102.
      IF(ABS(ONE-1.0)-2.E-2)102,102,101
  101 PRINT 10,REG,AA,BB,GG,ONE
   10 FORMAT(1H ,A6,  4E12.4)
C********** ERROR IN DIRECTIONAL COSINES.
      CALL ERPRNT(6HCHECK )
      STOP
C********** ADJUST ALPHA TO MAKE COSINES MORE ACCURATE.
C********** ADJUST COSINES
  102 SQ=SQRT(ONE)
      AA=AA/SQ
      BB=BB/SQ
      GG=GG/SQ
  104 RETURN
      END
      SUBROUTINE CNNOR(K)
C*************************************************************************
C********** SUBROUTINE CNNOR FINDS THE DIRECTIONAL COSINES
C********** OF THE NORMAL TO A POINT ON A CONE.
C*************************************************************************
       COMMON /69/          ABCO(20,200)        ,ALRAY(500)         ,BERAY(500)
     1 ,COORDS(6,50)      ,E(40,200)          ,EBASE(200)         ,ESOR(20,200)
     2 ,GARAY(500)        ,RED(20,200)        ,TITLE(12)          ,VMAT(20)
     3 ,VOL(200)          ,XLAM(200)          ,XRAY(500)          ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/      ALK(200)            ,ALPHA(40)          ,BEK(200)
     1 ,BETA(40)          ,DEV(200)           ,DK(200)            ,EK(200)
     2 ,ELAM(200)         ,ELAMAT(20)         ,EMAT(20)           ,ENERGY(200)
     3 ,GAK(200)          ,GAMMA(40)          ,REF(20)            ,SORMAT(20)
     4 ,SUMRAY(200)       ,SUMSOR(200)        ,X(40)              ,XK(200)
     5 ,Y(40)             ,YK(200)            ,Z(40)              ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                          IFLAG(40)           ,IPOINT(50)      ,
     *,ISMAX(50)          ,ISOR(20)           ,JF(200)            ,JFL(200)        ,
     *,JL(200)            ,JM(200)            ,JN(200)            ,JP(200)         ,
     *,JRAY(200)          ,JSOR(50)           ,KBND(900)          ,KFLAG(200)      ,
     *,KP(200)            ,KTYP(200)          ,LAMP(50)           ,LANGLE(20)      ,
     *,LREFL(200)         ,LTYPE(20)          ,MAT(200)           ,MFL(20)         ,
     *,MMAT(29)           ,NUMRAY(200)
      COMMON/PARAMS/               AL          ,ALN         ,ALR         ,ALRF        ,BE      ,
     *,BEN        ,BER        ,BERF        ,DIS         ,DMIN        ,DZ          ,EPS     ,
     *,GA         ,GAN        ,GAR         ,GARF        ,PER         ,
     *,SUMRA      ,XI         ,XNOW        ,XOLD        ,XREF        ,XTRAN       ,YI      ,
     *,YNOW       ,YOLD       ,YREF        ,YTRAN       ,ZI          ,
     *,ZNOW       ,ZOLD       ,ZREF        ,ZTRAN
      COMMON/IPARAM/               FMAX        ,IMAX        ,INOW        ,
     *,IOPRAY     ,IOPRNT     ,IR          ,IRAY        ,JMAX        ,JNOW        ,JOLD    ,
     *,KINT       ,KMAX       ,KNOW        ,MMAX        ,NNOW        ,NSOR
      INTEGER F,FMAX
      DELX=XNOW-XK(K)
      DELY=YNOW-YK(K)
      DELZ=ZNOW-ZK(K)
      SQ=SQRT(DK(K)**2*(DELX**2+DELY**2)+(1-DK(K))**2*DELZ**2)
C********** CALCULATE DIRECTIONAL COSINES OF NORMAL.
      ALN=DK(K)*DELX/SQ
      BEN=DK(K)*DELY/SQ
      GAN=(DK(K)-1.0)*DELZ/SQ
C********** CHECK DIRECTIONAL COSINES
      CALL CHECK(6HCNNOR ,ALN,BEN,GAN)
      CALL DEBUG(6HCNNOR )
      RETURN
      END
      SUBROUTINE CONREF(LL)
      COMMON /69/        ARCO(20,200)      ,ALRAY(500)       ,BERAY(500)
     1 ,CCCRCS(6,50)   ,E(40,200)        ,EBASE(200)       ,ESOR(20,200)
     2 ,GARAY(500)     ,RED(20,200)      ,TITLE(12)        ,VMAT(20)
     3 ,VOL(200)       ,XLAM(200)        ,XRAY(500)        ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/  ALK(200)          ,ALFMA(40)        ,BEK(200)
     1 ,BETA(40)       ,DEV(200)         ,DK(200)          ,EK(200)
     2 ,ELAM(200)      ,ELAMAT(20)       ,EMAT(20)         ,ENERGY(200)
     3 ,FAK(200)       ,GAMMA(40)        ,REF(20)          ,SORRV(20)
     4 ,SUMRAY(200)    ,SUMSOR(200)      ,X(40)            ,XK(200)
     5 ,Y(40)          ,YK(200)          ,Z(40)            ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                  IFLAG(40)       ,IPOINT(50)     ,
     *ISMAX(50)      ,ISOR(20)       ,JF(200)        ,JFL(200)       ,
     *JL(200)        ,JM(200)        ,JN(200)        ,JP(200)        ,
     *JRAY(200)      ,JSOR(50)       ,KBND(900)      ,KFLAG(200)     ,
     *KP(200)        ,KTYP(200)      ,LAMP(50)       ,LANGLE(20)     ,
     *LREFL(200)     ,LTYPE(20)      ,MAT(200)       ,MFL(20)        ,
     *NMAT(20)       ,NUMRAY(200)
      COMMON/PARAMS/        AL        ,ALN      ,ALR      ,ALRF     ,BE     ,
     *BEN      ,BER      ,BERF     ,DIS      ,DMIN     ,DZ       ,EPS    ,
     *GA       ,GAN      ,GAR      ,GARF     ,PER      ,
     *SUMRA    ,XI       ,XNOW     ,XOLD     ,XREF     ,XTRAN    ,YI     ,
     *YNOW     ,YOLD     ,YREF     ,YTRAN    ,ZI       ,
     *ZNOW     ,ZOLD     ,ZREF     ,ZTRAN
      COMMON/IPARAM/        FMAX      ,IMAX     ,INOW     ,
     *IOPRAY   ,IOPRNT   ,IR       ,IRAY     ,JMAX     ,JNOW     ,JOLD   ,
     *KINT     ,KMAX     ,KNOW     ,MMAX     ,MNOW     ,NSOR
      INTEGER F,FMAX
C********** SET PERCENT OF TRANSMISSION TO AN INPUT CONSTANT.
      FER=1.0-RED(LL,1)
      RETURN
      END
      SUBROUTINE CONNOR(K)
C*********************************************************************
C********* SUBROUTINE CONNOR CALCULATES THE DIRECTIONAL COSINES OF THE
C********* NORMAL TO A POINT ON THE SURFACE OF A CONIC.
C*********************************************************************
      COMMON /E9/         ABCO(20,200)       ,ALRAY(500)      ,BERAY(500)
     1 ,COORDS(6,50)  ,E(40,200)         ,EBASE(200)      ,ESOR(20,200)
     2 ,GARAY(500)    ,RED(20,200)       ,TITLE(12)       ,VMAT(20)
     3 ,VOL(200)      ,XLAM(200)         ,XRAY(500)       ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/  ALK(200)          ,ALPHA(40)       ,BEK(200)
     1 ,BETA(40)      ,DEV(200)          ,DK(200)         ,EK(200)
     2 ,ELAM(200)     ,ELAMAT(20)        ,EMAT(20)        ,ENERGY(200)
     3 ,GAK(200)      ,GAMMA(40)         ,REF(20)         ,SORMAT(20)
     4 ,SUMRAY(200)   ,SUMSOR(200)       ,X(40)           ,XK(200)
     5 ,Y(40)         ,YK(200)           ,Z(40)           ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                    IFLAG(40)      ,IPOINT(50)      ,
     *ISMAX(50)      ,ISOR(20)        ,JF(200)        ,JFL(200)        ,
     *JL(200)        ,JM(200)         ,JN(200)        ,JP(200)         ,
     *JRAY(200)      ,JSOR(50)        ,KBND(900)      ,KFLAG(200)      ,
     *KP(200)        ,KTYP(200)       ,LAMP(50)       ,LANGLE(20)      ,
     *LPFL(200)      ,LTYPE(20)       ,MAT(200)       ,MFL(20)         ,
     *MMAT(20)       ,NUMRAY(200)
      COMMON/PARAMS/     AL           ,ALN         ,ALR         ,ALRF        ,BE      ,
     *BEN      ,BER      ,BERF        ,DIS         ,DMIN        ,DZ          ,EPS     ,
     *GA       ,GAN      ,GAR         ,GARF        ,PER         ,
     *SUMMA    ,XI       ,XNOW        ,XOLD        ,XREF        ,XTRAN       ,YI      ,
     *YNOW     ,YOLD     ,YREF        ,YTRAN       ,ZI          ,
     *ZNOW     ,ZOLD     ,ZREF        ,ZTRAN
      COMMON/IPARAM/     FMAX         ,IMAX        ,INOW        ,
     *IOPRAY   ,IOPRNT   ,IR          ,IRAY        ,JMAX        ,JNOW        ,JOLD    ,
     *KINT     ,KMAX     ,KNOW        ,MMAX        ,MNOW        ,NSOR
      INTEGER F,FMAX
C********* CALCULATE LENGTH AND COSINES OF LINE FROM FOCUS TO POINT.
      DX=XNOW-XK(K)
      DY=YNOW-YK(K)
      R=SQRT(DX**2+DY**2)
      ALL=DX/R
      BEL=DY/R
      CALL CHECK(6HCONNOR,ALL,BEL,0.0)
C********* CALCULATE COS AND SIN OF ANGLE FROM AXIS TO LINE FROM
C********* FOCUS TO POINT ON SURFACE.
      COSTH=ALK(K)*ALL+BEK(K)*BEL
      SINTH=ALK(K)*BEL-BEK(K)*ALL
      DEN=SQRT(1.0+EK(K)**2-2.0*EK(K)*COSTH)
C********* CALCULATE COSINES OF NORMAL TO POINT ON SURFACE.
      ALN=(ALK(K)*COSTH-BEK(K)*SINTH-EK(K)*ALK(K))/DEN
      BEN=(ALK(K)*SINTH+BEK(K)*COSTH-EK(K)*BEK(K))/DEN
      GAN=0
C********* CHECK DIRECTIONAL COSINES.
      CALL CHECK(6HCONNOR,ALN,BEN,GAN)
      CALL DEBUG(6HCONNOR)
      RETURN
      END
```

```
                 SUBROUTINE CYL
C*****************************************************************************
C********* CYL HANDLES CASES WHERE COSTAN IS SMALL.
C********* PART OF HELIX INTERSECTION CALCULATION.
C*****************************************************************************
      COMMON /69/         ABCO(20,200)     ,ALRAY(500)       ,BERAY(500)
     1 ,COORDS(6,50)  ,E(40,200)        ,EBASE(200)       ,ESOR(20,200)
     2 ,GARAY(500)    ,RED(20,200)      ,TITLE(12)        ,WMAT(20)
     3 ,VOL(200)      ,XLAM(200)        ,XRAY(500)        ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/     ALK(200)         ,ALPHA(40)        ,REK(200)
     1 ,BETA(40)      ,DEV(200)         ,DK(200)          ,EK(200)
     2 ,ELAM(200)     ,ELAMAT(20)       ,EMAT(20)         ,ENERGY(200)
     3 ,GAK(200)      ,GAMMA(40)        ,REF(20)          ,SOMMAT(20)
     4 ,SUMRAY(200)   ,SUMSQR(200)      ,X(40)            ,XK(200)
     5 ,Y(40)         ,YK(200)          ,Z(40)            ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                    IFLAG(40)        ,IPOINT(50)       ,
     ,ISMAX(50)      ,ISOR(20)         ,JF(200)         ,JFL(200)         ,
     ,JL(200)        ,JM(200)          ,JN(200)         ,JP(200)          ,
     ,JRAY(200)      ,JSOR(50)         ,KBND(900)       ,KFLAG(200)       ,
     ,KP(200)        ,KTYP(200)        ,LAMP(50)        ,LANGLE(20)       ,
     ,LREFL(200)     ,LTYPE(20)        ,MAT(200)        ,MFL(20)          ,
     ,NMAT(20)       ,NUMRAY(200)
      COMMON/PARAMS/          AL         ,ALN        ,ALR        ,ALRF       ,BE        ,
     ,BEM      ,BER       ,BERF       ,DIS        ,DMIN       ,DZ         ,FPS       ,
     ,GA       ,GAM       ,GAR        ,GARF       ,PER        ,
     ,SUMRA    ,XI        ,XNOW       ,XOLD       ,XREF       ,XTRAN      ,YI        ,
     ,YNOW     ,YOLD      ,YREF       ,YTRAN      ,ZI         ,
     ,ZNOW     ,ZOLD      ,ZREF       ,ZTRAN
      COMMON/IPARAM/          FMAX       ,IMAX       ,INOW       ,
     ,IOPRAY   ,ICPRNT    ,IR         ,IRAY       ,JMAX       ,JNOW       ,JOLD      ,
     ,KINT     ,KMAX      ,KNOW       ,MMAX       ,NNOW       ,NSOR
      INTEGER F,FMAX
      COMMON/HELCOM/A,ABAR,B,B1,B1P,BP,CAP,DELTH,DELX,DELY,DELZ,DHIT,
     ,PSIZ,REV,RHO,STH,TH,TH1,SQRKS,RKS,CSTH,SNTH,RCSTH,RSNTH,BSTH,
     ,COSTAN,THZ,DTHZ
 12           CONTINUE
C********* CALCULATE STH AND BSTH
      CALL SOFTH
C********* CALCULATE TH AND DELTH
      CALL THOFS
C********* IF ITERATION HAS NOT CONVERGED, GO TO 12
      IF(ABS(DELTH).GT..01) GO TO 12
      DELS=SQRT((A**2-BSTH)/(1.-COSTAN**2))
      STHC=STH
      IF(STHC+2.*DELS.LT.0.) RETURN
      IF(STHC-2.*DELS.GT.DHIT) RETURN
      STH=STHC-DELS
C********* CALCULATE INTERSECTION DISTANCE.
      CALL RCYL
      IF(STH.LT.0) GO TO 14
      IF(STH.GT.DHIT) RETURN
      DHIT=STH
      RETURN
 14           CONTINUE
      STH=STHC+DELS
C********* FIND OTHER INTERSECTION
      CALL RCYL
      IF(0..LT.STH .AND. STH.LT.DHIT) DHIT=STH
      RETURN


      END
      SUBROUTINE CYLNOR(K)
C*********************************************************************
C********** CYLNOR CALCULATES DIRECTIONAL COSINES OF THE NORMAL TO A
C*********************************************************************
C********** POINT ON THE SURFACE OF A CYLINDER.
      COMMON /69/       ABCO(20,200)      ,ALRAY(500)      ,BERAT(500)
     1 ,COORCS(6,50)  ,E(40,200)         ,EBASE(200)      ,ESOR(20,200)
     2 ,GARAY(500)    ,RED(20,200)       ,TITLE(12)       ,VMAT(20)
     3 ,VOL(200)      ,XLAM(200)         ,XRAY(500)       ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/  ALK(200)          ,ALPHA(40)       ,BEK(200)
     1 ,BETA(40)      ,DEV(200)          ,DK(200)         ,EK(200)
     2 ,ELAM(200)     ,ELAMAT(20)        ,EMAT(20)        ,ENERGY(200)
     3 ,GAK(200)      ,GAMMA(40)         ,REF(20)         ,SONMAT(20)
     4 ,SUMRAY(200)   ,SUMSQR(200)       ,X(40)           ,XK(200)
     5 ,Y(40)         ,YK(200)           ,Z(40)           ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                 IFLAG(40)      ,IPOINT(50)       ,
     ,ISMAX(50)      ,ISOR(20)      ,JF(200)        ,JFL(200)         ,
     ,JL(200)        ,JM(200)       ,JN(200)        ,JP(200)          ,
     ,JRAY(200)      ,JSOR(50)      ,KBND(900)      ,KFLAG(200)       ,
     ,KF(200)        ,KTYP(200)     ,LAMP(50)       ,LANGLE(20)       ,
     ,LREFL(200)     ,LTYPE(20)     ,MAT(200)       ,MFL(20)          ,
     ,NMAT(20)       ,NUMRAY(200)
      COMMON/PARAMS/         AL       ,ALN      ,ALR      ,ALRF     ,BE      ,
     ,BEN      ,BER      ,BERF     ,DIS      ,DMIN     ,DZ       ,EPS     ,
     ,GA       ,GAN      ,GAR      ,GARF     ,PER      ,
     ,SUMGA    ,XI       ,XNOW     ,XOLD     ,XREF     ,XTRAN    ,YI      ,
     ,YNOW     ,YOLD     ,YREF     ,YTRAN    ,ZI       ,
     ,ZNOW     ,ZOLD     ,ZREF     ,ZTRAN
      COMMON/IPARAM/         FMAX     ,IMAX     ,INOW     ,
     ,IOPRAY   ,IOPRNT   ,IR       ,IRAY     ,JMAX     ,JNOW     ,JOLD    ,
     ,KINT     ,KMAX     ,KNOW     ,MMAX     ,NNOW     ,NSOR
      INTEGER F,FMAX
C********** CALCULATE COSINES OF VECTOR FROM POINT ON CYLINDRICAL AXIS
C********** TO POINT ON THE SURFACE OF THE CYLINDER.
      DELX=XNOW-XK(K)
      DELY=YNOW-YK(K)
      DELZ=ZNOW-ZK(K)
      CC=DELX*ALK(K)+DELY*BEK(K)+DELZ*GAK(K)
C********** CALCULATE COSINES OF NORMAL TO POINT ON SURFACE.
      ALN=(DELX-CC*ALK(K))/DK(K)
      BEN=(DELY-CC*BEK(K))/DK(K)
      GAN=(DELZ-CC*GAK(K))/DK(K)
C********** CHECK DIRECTIONAL COSINES.
      CALL CHECK(6HCYLNOR,ALN,BEN,GAN)
      CALL DEBUG(6HCYLNOR)
      RETURN
      END
      SUBROUTINE DCALC(N)
C*********************************************************************
C********* DCALC DETERMINES WHICH PART OF THE COIL TO LOOK IN AND
C********* WHICH TECHNIQUE TO USE TO CALCULATE THE INTERSECTION.
C********* PART OF HELIX INTERSECTION CALCULATION.
C*********************************************************************
       COMMON /69/       ASCO(20,200)    ,ALRAY(500)      ,BERAY(500)
      1 ,COORDS(6,50)   ,E(40,200)       ,ERASE(200)      ,ESDR(20,200)
      2 ,GARAY(500)     ,RED(20,200)     ,TITLE(12)       ,VMAT(25)
      3 ,VOL(200)       ,XLAM(200)       ,ARAY(500)       ,YRAY(500)
      4 ,ZRAY(500)
       COMMON /ARRAYS/  ALK(200)         ,ALPHA(40)       ,BEK(200)
      1 ,BETA(40)       ,DEV(200)        ,DK(200)         ,EK(200)
      2 ,ELAM(200)      ,ELAMAT(20)      ,EMAT(20)        ,ENERGY(200)
      3 ,GAK(200)       ,GAMMA(40)       ,REF(20)         ,SGMMAT(20)
      4 ,SUMRAY(200)    ,SUMSDR(200)     ,X(40)           ,XK(200)
      5 ,Y(40)          ,YK(200)         ,Z(40)           ,ZK(200)
      6 ,ZLAM(20)
       COMMON/IARRAY/                   IFLAG(40)       ,IPOINT(50)     ,
      ,ISMAX(50)      ,ISDR(20)        ,JF(200)        ,JFL(200)       ,
      ,JL(200)        ,JM(200)         ,JN(200)        ,JP(200)        ,
      ,JMAX(200)      ,JSDR(50)        ,KBND(500)      ,KFLAG(200)     ,
      ,KP(200)        ,KTMP(200)       ,LAMP(50)       ,LANGLE(20)     ,
      ,LREFL(200)     ,LTYPE(20)       ,MAT(200)       ,MFL(20)        ,
      ,NMAT(20)       ,NUMRAY(200)
       COMMON/PARAM/          AL        ,ALN       ,ALR       ,ALRF      ,BE       ,
      ,BEN      ,BEW      ,BERF      ,DIS       ,DMIN      ,DZ        ,EPS      ,
      ,GA       ,GAN      ,GAR       ,GARF      ,PER       ,
      ,SIGMA    ,XI       ,XNOW      ,XOLD      ,XREF      ,XTRAN     ,YI       ,
      ,YNOW     ,YOLD     ,YREF      ,YTRAN     ,ZI        ,
      ,ZNOW     ,ZOLD     ,ZREF      ,ZTRAN
       COMMON/IPARAM/         FMAX      ,IMAX      ,INOW      ,
      ,ICRAY    ,ICPRNT   ,IR        ,IRAY      ,JMAX      ,JNOW      ,JOLD     ,
      ,KTOT     ,KMAX     ,KNOW      ,MMAX      ,NNOW      ,NSCH
       INTEGER F,FMAX
       COMMON/HELCOM/A,ABAR,B,B1,B1P,BP,CAP,DELTH,DELX,DELY,DELZ,DHIT,
      ,PSIZ,REV,RHO,STH,TH,TH1,SGNKS,RKS,CSTH,SNTH,HCSTH,HSNTH,[illegible]STH,
      ,COSTAN,THZ,DTHZ
       DATA(NSTAR=4)
C******* CALCULATE PARAMETERS NEEDED.
       F=0
       RKS=RHO**2*CAP**2
       SQRKS=SQRT(RKS)
       PSI=PSIZ
       THZ=PSIZ+.5*REV
       DELZZ=DELZ
       DELZ =DELZ+N*REV*CAP
       F=0
       IDCF=0
       DTHZ=1.57
12                CONTINUE
       TH1=THZ+DTHZ
       TH=TH1
       DELTH=10.
C********** CALCULATE COSTAN(COS OF ANGLE BETWEEN RAY AND TANGENT)
       CALL COSTAN
       DTHZ=-DTHZ
14                CONTINUE
C********** CALCULATE S(TH).
       CALL SOFTH
       IF(ABS(DELTH).GT. .1) GO TO 145
      R=(TH1-TH)/DTHZ
      IF(RSTH.LT.2.*ABAR) GO TO 21
      IF(ABS(DELTH).LT..001) GO TO 15
145            CONTINUE
C********** CALCULATE TH(S).
      CALL THOFS
      GO TO 14
15             CONTINUE
      IF(IDCF.EQ.0) GO TO 16
      CALL ZCALC
      GO TO 9
16             CONTINUE
      IF(R.LT.-1. .OR.DTHZ.GT.0.) GO TO 9
      GO TO 12
21             CONTINUE
C********** SET SWITCH.
      ISW=6*IDCF+1
      IF(ABS(COSTAN).GT..3) ISW=ISW+3
      IF(R.GT.1.) ISW=ISW+2
      IF(R.LT.-1.) ISW=ISW+1
      IF(DTHZ.LT.0.) ISW=ISW+12
C********** BRANCH ON SWITCH.
      GO TO ( 23,27,27,29,27,27,25,23,22,24,
     6         22,22,24,23,12,26,22,12),ISW
C              1  2  3  4  5  6  7  8  9  0
C                                 D E C I S I O N   T A B L E
C  ISW     R        COSTAN  IDCF     DTHZ   STAT 1
C
C    1     0         SMALL    0        +     23       CYL,GO TO 9
C    2    -1         SMALL    0        +     27       GO TO 9
C    3    +1         SMALL    0        +     27       GO TO 9
C    4     0         LARGE    0        +     29       CHANGE SIGN,ZCALC,RET
C    5    -1         LARGE    0        +     27       GO TO 9
C    6    +1         LARGE    0        +     27       GO TO 9
C    7     0         SMALL    1        +     25       CYL,ZCALC,GO TO 9
C    8    -1         SMALL    1        +     23       CYL,GO TO 9
C    9    +1         SMALL    1        +     22       ZCALC,GO TO 9
C   10     0         LARGE    1        +     28       ZCALC (BOTH SIDES ARE
C   11    -1         LARGE    1        +     22       ZCALC,GO TO 9
C   12    +1         LARGE    1        +     22       ZCALC,GO TO 9
C   13     0         SMALL     0       -     24       CYL,GO TO 12
C   14    -1         SMALL     0       -     23       CYL,GO TO 9
C   15    +1         SMALL     0       -     12       GO TO 01
C   16     0         LARGE     0      -2L    26       SET IDCF
C   17    -1         LARGE     0      -2L    22       ZCALC (WITH TH.LT.THZ
C   18    +1         LARGE     0      -2L    12
C  %18                        1        -     --       IMPOSSIBLE
22             CONTINUE
      CALL ZCALC
      GO TO 9
23             CONTINUE
      CALL CYL
      GO TO 9
24             CONTINUE
      CALL CYL
      GO TO 12
25             CONTINUE
      CALL CYL
      CALL ZCALC
      GO TO 9
26             CONTINUE
      IDCF=1

     GO TO 12
27             CONTINUE
     GO TO 9
28             CONTINUE
     CALL ZCALC
29             CONTINUE
     DTHZ=-DTHZ
     CALL ZCALC
9              CONTINUE
     DELZ=DELZZ
     RETURN
     END
```

```
      SUBROUTINE DEBUG(RES)
C**********************************************************************
C********* SUBROUTINE DEBUG GIVES A DEBUG PRINT AND IS CALLED FROM
C*******   NUMEROUS ROUTINES.
C**********************************************************************
       COMMON /ES/          ABCD(20,200)      ,ALRAY(500)       ,BERAY(500)
     1 ,COORDS(6,50,       ,E(40,200)         ,EMASE(200)       ,ESOR(20,200)
     2 ,GARAY(500)         ,RED(20,200)       ,TITLE(12)        ,VMAT(20)
     3 ,VOL(200)           ,ALAM(200)         ,XRAY(500)        ,YRAY(500)
     4 ,ZRAY(500)
       COMMON /ARRAYS/  ALK(200)              ,ALPHA(40)        ,BEK(200)
     1 ,BETA(40)           ,DEK(200)          ,DK(200)          ,EK(200)
     2 ,ELAM(200)          ,ELMAT(20)         ,EMAT(20)         ,ENERGY(200)
     3 ,GAK(200)           ,GAMMA(40)         ,REF(20)          ,SUMMAT(20)
     4 ,SUMRAY(200)        ,SUMSQR(200)       ,X(40)            ,XK(200)
     5 ,Y(40)              ,YK(200)           ,Z(40)            ,ZK(200)
     6 ,ZLAM(20)
       COMMON/IARRAY/                        IFLAG(40)        ,IPOINT(50)      ,
     ,ISMAX(50)        ,ISOP(20)          ,JF(200)          ,JFL(200)        ,
     ,JL(200)          ,JM(200)           ,JN(200)          ,JP(200)         ,
     ,JMAX(200)        ,JSOR(50)          ,KBND(900)        ,KFLAG(200)      ,
     ,KP(200)          ,KTYP(200)         ,LAMP(50)         ,LANGLE(20)      ,
     ,LREFL(200)       ,LTYPE(20)         ,MAT(200)         ,MFL(20)         ,
     ,NMAT(20)         ,NUMRAY(200)
       COMMON/PARAMS/           AL          ,ALN        ,ALR        ,ALRF       ,RE       ,
     ,BEN       ,BER        ,BERF        ,DIS        ,DMIN       ,DZ         ,EPS      ,
     ,GA        ,GAN        ,GAR         ,GARF       ,PER        ,
     ,SUMAA     ,X1         ,XNO,        ,XOLD       ,XREF       ,XTRAN      ,YI       ,
     ,YNO,      ,YOLD       ,YREF        ,YTRAN      ,ZI         ,
     ,ZNO,      ,ZOLD       ,ZREF        ,ZTRAN
       COMMON/IPARAM/           FMAA        ,IMAX       ,INOW       ,
     ,IARRAY    ,ICOUNT     ,IR          ,IRAY       ,JMAA       ,JNOW       ,JOLD     ,
     ,KINT      ,KMAA       ,KNOW        ,MMAX       ,NNOW       ,NSOR
       INTEGER F,FMAA
       COMMON/DEBUG/  FRAC      ,IDEBUG
       IF(IDEBUG)100,100,101
  100  RETURN
  101  CONTINUE
       PRINT 10,RES
   10  FORMAT(16H0DEBUG PRINT IN ,A6)
       PRINT 11,JOLD,JNOW,INOW,IMAA,KNOW
   11  FORMAT(1H ,6H JOLD=,I12,6H JNOW=,I12,6H INOW=,I12,
      ,6H IMAA=,I12,6H KNOW=,I12)
       PRINT 12,AL,BE,GA,X1,Y1,Z1
   12  FORMAT(1H ,6H   AL=, E12.4,6H   BE=, E12.4,6H   GA=, E12.4,
      ,6H   X1=, E12.4,6H   Y1=, E12.4,6H   Z1=, E12.4)
       PRINT 13,ALR,BER,GAR,XREF,YREF,ZREF
   13  FORMAT(1H ,6H  ALR=, E12.4,6H  BER=, E12.4,6H  GAR=, E12.4,
      ,6H XREF=, E12.4,6H YREF=, E12.4,6H ZREF=, E12.4)
       PRINT 14,ALRF,BERF,GARF,XTRAN,YTRAN,ZTRAN
   14  FORMAT(1H ,6H ALRF=, E12.4,6H BERF=, E12.4,6H GARF=, E12.4,
      ,6H XTRAN, E12.4,6H YTRAN, E12.4,6H ZTRAN, E12.4)
       PRINT 15,ALN,BEN,GAN,XNO,YNO,ZNO
   15  FORMAT(1H 6H  ALN=, E12.4,6H  BEN=, E12.4,6H  GAN=, E12.4,
      ,6H XNO=, E12.4,6H YNO=, E12.4,6H ZNO=, E12.4)
       PRINT 16,DIS,DMIN,PER
   16  FORMAT(1H ,6H  DIS=, E12.4,6H DMIN=, E12.4,6H  PER=, E12.4)
       RETURN
       END
      SUBROUTINE DECIDE(IFLG)
C************************************************************************
C********** SUBROUTINE DECIDE DETERMINES IF A NEW RAY IS NEEDED.
C************************************************************************
      COMMON /69/       ACCO(20,200)      ,ALRAY(500)        ,BERAY(500)
     1 ,CCORDS(6,50)    ,EI-C(200)        ,EBASE(200)        ,ESCR(20,200)
     2 ,GARAY(500)      ,REC(20,200)      ,TITLE(12)         ,VMAT(20)
     3 ,VOL(200)        ,XLAM(200)        ,XRAY(500)         ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/   ALC(200)          ,ALPHA(40)         ,BEK(200)
     1 ,BETA(40)        ,DEV(200)         ,DK(200)           ,EK(200)
     2 ,ELAM(200)       ,ZLAMAT(20)       ,EMAT(20)          ,ENERGY(200)
     3 ,GAK(200)        ,GAMMA(40)        ,REF(20)           ,SUMMAT(20)
     4 ,SUMRAY(200)     ,SUMSQR(200)      ,X(40)             ,XK(200)
     5 ,Y(40)           ,YK(200)          ,Z(40)             ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                    IFLAG(40)          ,IPOINT(50)      ,
     ,ISMAX(50)     ,ISCR(20)         ,JF(200)           ,JFL(200)        ,
     ,JL(200)       ,JM(200)          ,JN(200)           ,JP(200)         ,
     ,JRAY(200)     ,JSCR(50)         ,KEND(900)         ,KFLAG(200)      ,
     ,KP(200)       ,KTYP(200)        ,LAMP(50)          ,LANGLE(20)      ,
     ,LREFL(200)    ,LTYPE(20)        ,MAT(200)          ,MFL(20)         ,
     ,NMAT(20)      ,NUMRAY(200)
      COMMON/PARAMS/         AL        ,ALN        ,ALR        ,ALRF       ,BE      ,
     ,BEN       ,BER       ,BERF       ,DIS        ,DMIN       ,DZ         ,EPS     ,
     ,GA        ,GAN       ,GAR        ,GARF       ,PER        ,
     ,SUMRA     ,XI        ,XNOW       ,XOLD       ,XREF       ,XTRAN      ,YI      ,
     ,YNOW      ,YOLD      ,YREF       ,YTRAN      ,ZI         ,
     ,ZNOW      ,ZOLD      ,ZREF       ,ZTRAN
      COMMON/IPARAM/         FMAX      ,IMAX       ,INOW       ,
     ,IORRAY    ,ICRRNT    ,IR         ,IRAY       ,JMAX       ,JNOW       ,JOLD    ,
     ,KINT      ,KMAX      ,KNOW       ,MMAX       ,NNOW       ,NSCR
      INTEGER F,FMAX
C********** ZERO BOUNDARY FLAGS.
      DO 103 K=1,KMAX
  103 KFLAG(K)=0
C********** IF REFLECTED RAY DID NOT SURVIVE, ADJUST IMAX.
  120 DO 113 F=1,FMAX
      IF(E(IMAX,F))113,113,121
  113 CONTINUE
C********** SET FLAG TO INDICATE RAY DEAD.
      IFLAG(IMAX)=0
  122 IMAX=IMAX-1
  121 CONTINUE
C********** DETERMINE IF RAY SURVIVED.
      I=INOW
      DO 112 F=1,FMAX
      IF(E(I,F))112,112,101
  112 CONTINUE
C********** SET FLAG TO INDICATE RAY DEAD.
      IFLAG(I)=0
      GO TO 100
C********** RAY SURVIVED. ADJUST PARAMETERS.
  101 IFLG=0
      AL=ALPHA(INOW)
      BE=BETA(INOW)
      GA=GAMMA(INOW)
      XI=X(INOW)
      YI=Y(INOW)
      ZI=Z(INOW)
      XOLD=XI
      YOLD=YI
      ZOLD=ZI
      RETURN
C********** RAY DID NOT SURVIVE. SET FLAG AND RETURN.
  100 IFLG=-1
      RETURN
      END
      SUBROUTINE DEPOS
C*********************************************************************
C********** SUBROUTINE DEPOS DEPOSITES ENERGY IN THE SEGMENT WHICH
C********** WAS CROSSED BY A RAY.
C*********************************************************************
      COMMON /E5/      ABCO(20,200)      ,ALRAY(500)       ,BERAY(500)
     1 ,COORDS(6,50)  ,E(40,200)         ,EBASE(200)       ,ESOR(20,200)
     2 ,GARAY(500)    ,RED(20,200)       ,TITLE(12)        ,VMAT(20)
     3 ,XOL(200)      ,XLAM(200)         ,XRAY(500)        ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/  ALK(200)          ,ALPHA(40)        ,BEK(200)
     1 ,BETA(40)      ,DEK(200)          ,DK(200)          ,EK(200)
     2 ,ELAM(200)     ,ELAMAT(20)        ,EMAT(20)         ,ENERGY(200)
     3 ,GAK(200)      ,GAMMA(40)         ,REF(20)          ,SGRMAT(20)
     4 ,SUMRAY(200)   ,SUMSQR(200)       ,X(40)            ,XK(200)
     5 ,Y(40)         ,YK(200)           ,Z(40)            ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                  IFLAG(40)       ,IPOINT(50)       ,
     ,ISMAX(50)     ,ISOR(20)         ,JF(200)        ,JFL(200)         ,
     ,JL(200)       ,JM(200)          ,JN(200)        ,JP(200)          ,
     ,JRAY(200)     ,JSOR(50)         ,KEND(500)      ,KFLAG(200)       ,
     ,KP(200)       ,KTYP(200)        ,LAMP(50)       ,LANGLE(20)       ,
     ,LREFL(200)    ,LTYPE(20)        ,MAT(200)       ,MFL(20)          ,
     ,NMAT(20)      ,NUMRAY(200)
      COMMON/PARAMS/       AL          ,ALN        ,ALR        ,ALRF       ,RE      ,
     ,BEN       ,BER       ,BERF       ,DIS        ,DMIN       ,DZ         ,EPS     ,
     ,GA        ,GAN       ,GAR        ,GARF       ,PER        ,
     ,SUMRA     ,XI        ,XNOW       ,XOLD       ,XREF       ,XTRAN      ,YI      ,
     ,YNOW      ,YOLD      ,YREF       ,YTRAN      ,ZI         ,
     ,ZNOW      ,ZOLD      ,ZREF       ,ZTRAN
      COMMON/IPARAM/       FMAX        ,IMAX       ,INOW       ,
     ,ICPRAY    ,ICPRNT    ,IR         ,IRAY       ,JMAX       ,JNOW       ,JOLD    ,
     ,KINT      ,KMAX      ,KNOW       ,MMAX       ,MNOW       ,NSOR
      INTEGER F,FMAX
C********** SET SEGMENT INDEX.
      J=JNOW
C********** SET MATERIAL INDEX.
      M=MAT(J)
C********** SET RAY INDEX.
      I=INOW
      DO 102 F=1,FMAX
      IF(ABCO(M,F))103,102,100
  100 EOLD=E(I,F)
C********** CALCULATE NEW RAY ENERGY.
      E(I,F)=EOLD*EXP(-ABCO(M,F)*DMIN)
C********** DEPOSIT ENERGY LOST BY RAY IN SEGMENT.
      SUMRAY(J)=SUMRAY(J)+EOLD-E(I,F)
C********** GET SCALE FACTOR
      CALL SCALE(M,XLAM,F,SCA)
C********** SCALE ENERY DEPOSITED.
      ELAM(J)=ELAM(J)+(EOLD-E(I,F))*SCA
  102 CONTINUE
  101 JFL(J)=I
      MFL(M)=I
C********** UPDATE NUMBER OF RAYS PASSING THROUGH SEGMENT.
      JRAY(J)=JRAY(J)+1
      CALL DEBUG(6H DEPOS)
      RETURN
      END
      SUBROUTINE DIFREF(LL)
C****************************************************************************
C********** DIFREF CALCULATES DIFFUSE REFLECTION
C****************************************************************************
      COMMON /69/     AECO(20,200)      ,ALRAY(500)        ,BERAY(500)
     1 ,COORDS(6,50)  ,E(40,200)        ,EBASE(200)        ,ESOM(20,200)
     2 ,GARAY(500)    ,RED(20,200)      ,TITLE(12)         ,VMAT(20)
     3 ,VOL(200)      ,XLAM(200)        ,XRAY(500)         ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/  ALK(200)         ,ALPHA(40)         ,BEK(200)
     1 ,BETA(40)      ,DEV(200)         ,DK(200)           ,EK(200)
     2 ,FLAM(200)     ,ELAMAT(20)       ,EMAT(20)          ,ENERGY(200)
     3 ,GAK(200)      ,GAMMA(40)        ,REF(20)           ,SUMAT(20)
     4 ,SUMRAY(200)   ,SUMSQM(200)      ,X(40)             ,XK(200)
     5 ,Y(40)         ,YK(200)          ,Z(40)             ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                    IFLAG(40)      ,IPOINT(50)      ,
     *ISMAX(50)     ,ISOR(20)        ,JF(200).        ,JFL(200)        ,
     *JL(200)       ,JM(200)         ,JN(200)         ,JP(200)         ,
     *JRAY(200)     ,JSOR(50)        ,KBND(999)       ,KFLAG(200)      ,
     *KP(200)       ,KTYP(200)       ,LAMP(50)        ,LANGLE(20)      ,
     *LREFL(200)    ,LTYPE(20)       ,MAT(200)        ,MFL(20)         ,
     *NMAT(20)      ,NUMRAY(200)
      COMMON/PARAMS/         AL        ,ALN        ,ALR        ,ALRF       ,BE      ,
     *BEN        ,BER        ,BERF       ,DIS        ,DMIN       ,DZ         ,EPS     ,
     *GA         ,GAN        ,GAR        ,GAMF       ,PER        ,
     *SUMRA      ,XI         ,XNOW       ,XOLD       ,XREF       ,XTRAN      ,YI      ,
     *YNOW       ,YOLD       ,YREF       ,YTRAN      ,ZI         ,
     *ZNOW       ,ZOLD       ,ZREF       ,ZTRAN
      COMMON/IPARAM/         FMAX       ,IMAX       ,INC,       ,
     *IOPRAY     ,IOPRNT     ,IR         ,IRAY       ,JMAX       ,JNOW       ,JOLD    ,
     *KINT       ,KMAX       ,KNOW       ,MMAX       ,NNIO       ,NSOR
      INTEGER F,FMAX
C********** CALCULATE RANDOM DELX, DELY, AND DELZ FOR POINT.
  101 DELX=2.0*RAND(0)-1.0
      DELY=2.0*RAND(0)-1.0
      IF(1.0-DELX**2-DELY**2)101,107,107
  107 DELZ=SQRT(1.0-DELX**2-DELY**2)
      IF(1.0-ALN**2)106,106,102
  106 ALP=0.0
      BEP=1.0
      GAP=0.0
      GO TO 105
  102 SQ=SQRT(1.0-ALN**2)
      ALP=(1.0-ALN**2)/SQ
      BEP=-ALN*BEN/SQ
      GAP=-ALN*GAN/SQ
  105 ALQ=BEN*GAP-BEP*GAN
      BEQ=ALP*GAN-ALN*GAP
      GAQ=ALN*BEP-ALP*BEN
C********** CALCULATE DIRECTIONAL COSINES FOR REFLECTED RAY
      ALR=DELX*ALP+DELY*ALQ+DELZ*ALN
      BER=DELX*BEP+DELY*BEQ+DELZ*BEN
      GAR=DELX*GAP+DELY*GAQ+DELZ*GAN
C********** GET COS ANGLE OF REFLECTED RAY WITH NORMAL
      COSTM=ALR*ALN+GAR*GAN+BER*BEN
C********** GET COS ANGLE OF IMPENDING RAY WITH NORMAL
      COSANG=AL*ALN+BE*BEN+GA*GAN
C********** IS REFLECTED RAY ON REFLECTION SIDE OF SURFACE?
      IF(COSTM*COSANG)104,104,103
C********** CHANGE DIRECTION OF REFLECTED RAY
  103 ALR=-ALR
      BER=-BER
      GAR=-GAR
C********** CALCULATE PERCENT OF TRANSMISSION
  104 PER=1.0-RED(LL,1)
C********** CHECK DIRECTIONAL COSINES.
      CALL CHECK(6HDIFREF,ALR,BER,GAR)
      RETURN
      END
      SUBROUTINE DSUB(MSTAR)
C*****************************************************************************
C********** DSUB STEPS THROUGH THE PROPER ANGLES TO ISOLATE AND
C********** FIND ANY ROOTS THAT MAY EXIST FOR COIL N.
C********** PART OF HELIX INTERSECTION CALCULATION.
C*****************************************************************************
      COMMON /69/        ARC(20,200)      ,ALRAY(500)      ,BERAY(500)
     1 ,COEFFS(6,50)  ,E(40,200)        ,EBASE(200)      ,ESQR(20,200)
     2 ,GARAY(500)    ,RED(20,200)      ,TITLE(12)       ,VMAT(20)
     3 ,VOL(200)      ,XLAM(200)        ,XRAY(500)       ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/  ALK(200)         ,ALPHA(40)       ,BEK(200)
     1 ,BETA(40)      ,DEV(200)         ,DK(200)         ,EK(200)
     2 ,FLAM(200)     ,ELAMAT(20)       ,EMAT(20)        ,ENERGY(200)
     3 ,GAK(200)      ,GAMMA(40)        ,REF(20)         ,SQMAT(20)
     4 ,SUMRAY(200)   ,SUMSQR(200)      ,X(40)           ,XK(200)
     5 ,Y(40)         ,YK(200)          ,Z(40)           ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                    IFLAG(40)      ,IPOINT(50)     ,
     *ISMAX(50)     ,ISQR(20)     ,JF(200)        ,JFL(200)       ,
     *JL(200)       ,JM(200)      ,JN(200)        ,JP(200)        ,
     *JRAY(200)     ,JSQR(20)     ,KBND(900)      ,KFLAG(200)     ,
     *KP(500)       ,KTYP(200)    ,LAMP(50)       ,LANGLE(20)     ,
     *LEFFL(200)    ,LTYPE(20)    ,MAT(200)       ,MFL(20)        ,
     *NMAT(20)      ,NUMRAY(200)
      COMMON/PARAMS/       AL        ,ALN      ,ALR      ,ALRF     ,BE     ,
     *BEN     ,BER      ,BERF      ,DIS      ,CMIN     ,DZ       ,EPS    ,
     *GA      ,GAN      ,GAR       ,GARF     ,PER      ,
     *SUMRA   ,XI       ,XNOW      ,XOLD     ,XREF     ,XTRAN    ,YI     ,
     *YNOW    ,YOLD     ,YREF      ,YTRAN    ,ZI       ,
     *ZNOW    ,ZOLD     ,ZREF      ,ZTRAN
      COMMON/IPARAM/       FMAX      ,IMAX     ,INOW     ,
     *IOARAY  ,ICPRNT   ,IR        ,IRAY     ,JMAX     ,JNOW     ,JOLD   ,
     *KINT    ,KMAX     ,KNOW      ,MMAX     ,MNOW     ,NSOR
      INTEGER F,FMAX
      COMMON/HELCOM/A,ABAR,B,B1,B1P,BP,CAP,DELTH,DELX,DELY,DELZ,DHIT,
     *PSIZ,RFK,RHO,STH,TH,TH1,SQRKS,RKS,CSTH,SNTH,RCSTH,RSNTH,BSTH,
     *COSTAN,THZ,DTHZ
  101 M=0
C********** STORE PREVIOUS ANGLE.
  102 TH1=TH
      B1=B
      B1P=BP
C********** ADVANCE STEP COUNTER.
      M=M+1
C********** CALCULATE NEW ANGLE.
      TH=TH+DELTH
C********** CALCULATE B AND BP.
      CALL BCALC
C********** IF SIGN REVERSAL CALL REVS.
      IF(BP*B1P)103,104,104
  103 CALL REVS
C********** IF MOVING AWAY FROM ROOT AND B GREATER THAN ABAR GO TO NEXT S
      IF(DELTH*BP)106,105,105
  105 IF(B-ABAR)106,106,111
C********** IF MOVING AWAY FROM ROOT, CALL INFL.
  104 IF(DELTH*BP)108,108,107
  107 CALL INFL(IFL)
C********** IF A CHANGE OF SIGN WAS FOUND, GO TO NEXT STEP(106).
      IF(IFL)106,106,115
C********** IF B LESS THAN ABAR, GO TO NEXT STEP.
  115 IF(B-ABAR)106,106,111
C********** IF ROOT IS BRACKETED, FIND ROOT.
  108 IF((B-ABAR)*(B1-ABAR))109,109,106
  109 CALL FINDR
C********** IF MORE STEPS, GO TO 102.
  106 IF(M-MSTAR)102,111,111
  111 CONTINUE
  110 RETURN
      END
```

```
FTN5,5A
                                                                  05/29/71
      SUBROUTINE EDIT
C.........................................................................EDIT
C.......... SUBROUTINE EDIT PRINTS FINAL ANSWERS..........................................
C.........................................................................EDIT
      COMMON /69/            ABSP(20,200)      ,ALPHAY(500)       ,BETAY(500)
     1 ,CSCRDS(6,50)   ,E(40,200)       ,EPASE(200)       ,ESQR(20,200)
     2 ,GAPAY(500)     ,MED(20,200)     ,TITLE(12)        ,YMAT(20)
     3 ,VEL(200)       ,XLAM(200)       ,XRAY(500)        ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/  ALK(200)          ,ALPHA(40)        ,BEK(200)
     1 ,BETA(40)       ,DEV(200)         ,DK(200)          ,EK(200)
     2 ,ELAM(200)      ,ELAMAT(20)       ,EMAT(20)         ,ENERGY(200)
     3 ,GAK(200)       ,GAMMA(40)        ,REF(20)          ,SQRMAT(20)
     4 ,SUMRAY(200)    ,SUMSQR(200)      ,X(40)            ,XO(200)
     5 ,Y(40)          ,YK(200)          ,Z(40)            ,ZO(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/
                                        IFLAG(40)       ,IPRINT(50)     ,
     ,ISMAX(50)        ,ISRM(20)        ,JF(200)        ,JFL(200)       ,
     ,JL(200)          ,JM(200)         ,JN(200)        ,JP(200)        ,
     ,JRAY(200)        ,JSEM(50)        ,KRAD(900)      ,KFLAG(200)     ,
     ,KP(200)          ,KTYP(200)       ,LAMP(50)       ,LANGLE(20)     ,
     ,LREFL(200)       ,LTYPE(20)       ,MAT(200)       ,MFL(20)        ,
     ,NMAT(20)         ,NUMRAY(200)
      COMMON/PARAMS/           AL
                                        ,ALN       ,ALM       ,ALRF      ,BE
     ,BEN       ,BEM       ,BERF        ,DIS       ,DMIN      ,DZ        ,EPS   ,
     ,GA        ,GAN       ,GAR         ,GARF      ,PEM       ,
     ,SUMRA     ,XO        ,XNEW        ,XFLD      ,XREF      ,XTRAN     ,YI    ,
     ,YAS.      ,YOLD      ,YREF        ,YTRAN     ,ZI        ,
     ,ZAS.      ,ZOLD      ,ZREF        ,ZTRAN
      COMMON/IPARAM/           FMAX        ,IMAX      ,INEW      ,
     ,IEPRAY    ,IMPRNT     ,IP          ,IRAY      ,JMAX      ,JNEW      ,JOLD  ,
     ,MIST      ,KMAX       ,KNEW        ,MMAX      ,NNEW      ,NSEM
      INTEGER F,FMAX
C.......... CALCULATE TOTAL ENERGY IN SYSTEM,
      DIV=FLOAT(IRAY)/(IRAY-1)                                         EDIT
      ALIN=0
C.......... PRINT PAGE HEADING,                                        EDIT
      PRINT 20                                                         EDIT
   20 FORMAT(1H1,53X,15HSEGMENT RESULTS/)                              EDIT
C.......... CALCULATE TOTAL ENERGY DEPOSITED,                          EDIT
      SUME=0.0                                                         EDIT
      SUMLAM = 0.                                                      EDIT
      DO 100 J=1,JMAX
      SUMLAM = SUMLAM + ELAM(J)                                        EDIT
  100 SUME=SUME+ENERGY(J)
C.......... CALCULATE PERCENT ERROR FOR EACH SEGMENT,                  EDIT
      DO 120 J=1,JMAX                                                  EDIT
      IF(NUMRAY(J)-3)121,121,122                                       EDIT
  121 DEV(J)=100.0                                                     EDIT
      GO TO 120                                                        EDIT
  122 IF(ENERGY(J)-1.E-8)121,121,126                                   EDIT
  126 DEV(J)=SQRT(DIV*(SUMSQR(J)-(ENERGY(J)**2)/IRAY))/ENERGY(J)
  120 CONTINUE
C.......... PRINT PAGE HEADING,                                        EDIT
      PRINT 10                                                         EDIT
   10 FORMAT(1H0,6HOTHER,2X,8HDAUGHTER,1X,8HMATERIAL,1X,5HTOTAL,4X,    EDIT
           1  6HSCALED,5X,5HTOTAL,4X,6HSCALED,4X,7HSEGMENT,2X,7HPERCENT,1X,
           2  7HPERCENT,2X,7HPERCENT,1X,5HTOTAL,4X,5HTOTAL/
           3  1H ,7HSEGMENT,1X,7HSEGMENT,2X,4HTYPE,5X,7HSEGMENT,2X,7HSEGMENT,
           4  2X,6HPOWER ,3X,6HPOWER ,4X,6HVOLUME,3X,5HTOTAL,3X,8HERROR IN,2X,
           5  6HSCALED,2X,8HRAY LEGS,1X,4HRAYS/
           6  1H ,6HNUMBER,2X,6HNUMBER,3X,6HNUMBER,3X,6HPOWER ,3X,6HPOWER ,3X,
           7  7HDENSITY,2X,7HDENSITY,3X,4HUSED,5X,6HPOWER ,2X,9HTOTAL PCT,1X,
           8  6HPOWER ,2X,7HIN SEG,,2X,7HIN SEG,/)
      C......... LOOP THROUGH ALL SEGMENTS.                                       EDIT
            DO 131 MEM=1,LMAX                                                     EDIT
            IF(LF(MEM))132,101,132                                                EDIT
      C......... PRINT MOTHER SEGMENT NUMBER.                                     EDIT
        132 PRINT 12,MEM                                                          EDIT
         12 FORMAT(1H ,I6)
            NLINE=NLINE+1
      C......... SET UP FIRST DAUGHTER SEGMENT.                                   EDIT
            J=LF(MEM)                                                             EDIT
      C......... SPECIAL PRINTOUT FOR SEG 1 RESULTS
            IF(MEM-1) 134,134,103
        134 J = 1
        103 M=MAT(J)                                                              EDIT
            IF(VOL(J))104,105,104
      C......... CALCULATE ENERGY/UNIT VOLUME FOR SEGMENT J.                      EDIT
        104 EVOL=ENERGY(J)/VOL(J)                                                 EDIT
            EVOLAM = ELAM(J)/VOL(J)
            GO TO 106                                                             EDIT
        105 EVOL=0.0                                                              EDIT
            EVOLAM = 0.
      C......... CALCULATE PERCENT ENERGY/UNIT VOLUME.                            EDIT
        106 ENTOT=ENERGY(J)/SUME
            ENTLAM = ELAM(J)/SUMLAM
      C......... PRINT RESULTS FOR A GIVEN SEGMENT.                               EDIT
            PRINT 15,J,M,ENERGY(J),ELAM(J),EVOL,EVOLAM,VOL(J),ENTOT,DEV(J),
           1  ENTLAM,JRAY(J),NUMRAY(J)
         15 FORMAT(1H ,6X,2I8,3X,4E9.2,E10.2,2X,2PF6.2,2(3X,2PF6.2),2I8)
            NLINE=NLINE+1                                                         EDIT
      C......... IF LINE COUNT EXCEEDS 50, EJECT AND PRINT HEADING.               EDIT
            IF(NLINE-50)130,130,131                                               EDIT
        131 PRINT 20                                                              EDIT
            PRINT 10                                                              EDIT
            NLINE=6                                                               EDIT
        130 CONTINUE                                                              EDIT
      C......... IF JUST PRINTED SEG 1 RESULTS, GET DAUGHTER
            IF(J-1) 133,135,133
        135 J = LF(MEM)
            GOTO 103
      C......... SET UP NEXT DAUGHTER.                                            EDIT
        133 J = LN(J)
      C......... IF MORE DAUGHTERS, GO TO 103.                                    EDIT
            IF(J)103,101,103
        101 CONTINUE                                                              EDIT
      C......... PRINT TITLE, TOTAL SEGMENT AND RAY ENERGIES.                     EDIT
            PRINT 18                                                              EDIT
         18 FORMAT(1H1,53X,16HMATERIAL RESULTS/)                                  EDIT
      C......... PRINT HEADING.                                                   EDIT
            PRINT 10                                                              EDIT
      16 FERMAT(1H ,8HMATERIAL,1X,5HTETAL,4X,6HSCALED,3X,5HTETAL,4X,
        1  6HSCALED,3X,8HMATERIAL,1X,7HPERCENT,1X,7HPERCENT,3X,7HPERCENT,
        2  1X,5HTETAL,4X,5HTETAL/
        3  1H ,4HTYPE,5X,8HMATERIAL,1X,8HMATERIAL,1X,6HPEWER ,3X,6HPEWER ,
        4  3X,6HVELUME,3X,5HTETAL,3X,8HERRER IN,2X,6HSCALED,2X,7HRAYS IN,
        5  2X,8HSEGMENTS/
        7  1H ,6HNUMBER,3X,6HPEWER ,3X,6HPEWER ,3X,7HDENSITY,2X,7HDENSITY,
        8  2X,4HUSED,5X,6HPEWER ,2X,9HTETAL PCT,1X,6HPEWER ,2X,8HMATERIAL,
        9  1X,7HEF MAT,/)
C********* SUM MATERIAL ENERGIES, VELUMES, AND SEGMENTS
           DE 132 M=1,MMAX
             MFL(M) = 0
     132 CENTINUE
           DE 107 J=1,JMAX
           M=MAT(J)
           IF(M)107,107,108
     108 EMAT(M)=EMAT(M)+ENERGY(J)
           VMAT(M)=VMAT(M)+VEL(J)
           ELAMAT(M)=ELAMAT(M)+ELAM(J)
           MFL(M) = MFL(M) + 1
     107 CENTINUE                                                        EDIT
C********* LEEP THREUGH ALL MATERIALS.
           DE 109 M=1,MMAX                                               EDIT
C********* IF REF.ACTIVE INDEX = 0.0, MATERIAL DEES NET EXIST.
           IF(REF(M))109,109,110                                         EDIT
C********* CALCULATE PERCENT EF TETAL ENERGY ABSERBED IN MATERIAL M.    EDIT
     110 PERC=EMAT(M)/SUME
           PERLAM = ELAMAT(M)/SUMLAM                                      EDIT
C********* CALCULATE PERCENT ERRER FER MATERIAL.                        EDIT
           EN=NMAT(M)                                                    EDIT
           IF(NMAT(M)-3)123,123,124                                      EDIT
     123 DEVM=100.0                                                       EDIT
           GE TE 125
     124 IF(EMAT(M)-1.E-6)123,123,127
     127 DEVM=SQRT(SUMMAT(M)-(EMAT(M)**2)/IRAY)/EMAT(M)                  EDIT
     125 CENTINUE
           IF(VMAT(M))112,112,111                                        EDIT
C********* CALCULATE ENERGY/UNIT VELUME FER MATERIAL M.
     111 EVEL=EMAT(M)/VMAT(M)
           EVELAM = ELAMAT(M)/VMAT(M)
           GE TE 113
     112 EVEL=0.0
           EVELAM = 0.
     113 CENTINUE                                                         EDIT
C********* PRINT RESULTS FER A GIVEN MATERIAL.
           PRINT 17,M,EMAT(M),ELAMAT(M),EVEL,EVELAM,VMAT(M),PERC,DEVM,PERLAM,
        1  NMAT(M),MFL(M)
      17 FERMAT(1H ,I6,2X,3E9.2,2(2X,2PF6.2),4X,2PF6.2,I7,I9)
     109 CENTINUE
C********* PRINT SUMMARY RESULTS
           PRINT 11,SUME,SUMLAM,SUMRA,IRAY,IR
      11 FERMAT(1H0,/////////26H SUMMARY RESULTS//
          *1H ,22HTETAL ABSERBED PEWER =,E12.4/
          *1H ,22HTETAL SCALED PEWER   =,E12.4/
          *1H ,22HTETAL SEURCE PEWER   =,  E12.4/1H ,                    EDIT
          *22HTETAL NUMBER EF RAYS =,I12/
          *1H ,22HFINAL RANDEM INTEGER =,I12)                            EDIT
           RETURN                                                        EDIT
           END
      SUBROUTINE ELLNOR(K)
C*********************************************************************
C********* ELLNOR CALCULATES DIRECTIONAL COSINES OF NORMAL
C********* TO A POINT ON AN ELLIPSOID OF REVOLUTION.
C*********************************************************************
       COMMON /69/      ABCO(20,200)       ,ALRAY(500)      ,BERAY(500)
      1 ,COORDS(6,50)   ,E(40,200)         ,EBASE(200)      ,ESOR(20,200)
      2 ,GARAY(500)     ,RED(20,200)       ,TITLE(12)       ,YMAT(20)
      3 ,VOL(200)       ,XLAM(200)         ,XRAY(500)       ,YRAY(500)
      4 ,ZRAY(500)
       COMMON /ARRAYS/  ALK(200)           ,ALPHA(40)       ,BEK(200)
      1 ,BETA(40)       ,DEV(200)          ,DK(200)         ,EK(200)
      2 ,ELAM(200)      ,ELAMAT(20)        ,EMAT(20)        ,ENERGY(200)
      3 ,GAK(200)       ,GAMMA(40)         ,REF(20)         ,SQRMAT(20)
      4 ,SUMRAY(200)    ,SUMSQR(200)       ,X(40)           ,XK(200)
      5 ,Y(40)          ,YK(200)           ,Z(40)           ,ZK(200)
      6 ,ZLAM(20)
       COMMON/IARRAY/                  IFLAG(40)       ,IPOINT(50)      ,
      ,ISMAX(50)      ,ISQR(20)        ,JF(200)        ,JFL(200)        ,
      ,JL(200)        ,JM(200)         ,JN(200)        ,JP(200)         ,
      ,JRAY(200)      ,JSCP(50)        ,KBND(920)      ,KFLAG(200)      ,
      ,KP(200)        ,KTYP(200)       ,LAMP(50)       ,LANGLE(20)      ,
      ,LREFL(200)     ,LTYPE(20)       ,MAT(200)       ,MFL(20)         ,
      ,NMAT(20)       ,NUMRAY(200)
       COMMON/PARAMS/         AL        ,ALN      ,ALR      ,ALRF     ,BE     ,
      ,BEN      ,BER      ,BERF     ,DIS      ,DMIN     ,DZ       ,EPS    ,
      ,GA       ,GAN      ,GAR      ,GARF     ,PER      ,
      ,SUMRA    ,XI       ,XNOW     ,XOLD     ,XREF     ,XTRAN    ,YI     ,
      ,YNOW     ,YOLD     ,YREF     ,YTRAN    ,ZI       ,
      ,ZNOW     ,ZOLD     ,ZREF     ,ZTRAN
       COMMON/IPARAM/         FMAX      ,IMAX     ,INOW     ,
      ,ICPRAY   ,ICPRNT   ,IR       ,IRAT     ,JMAX     ,JNOW     ,JOLD   ,
      ,KINT     ,KMAX     ,KNOW     ,MMAX     ,MNOW     ,NSOR
       INTEGER F,FMAX
C********** CALCULATE X,Y,Z COMPONENTS OF NORMAL VECTOR.
       DELXA=(XNOW-XK(K))/DK(K)
       DELYA=(YNOW-YK(K))/DK(K)
       DELZB=(ZNOW-ZK(K)-EK(K))/EK(K)**2
C********** CALCULATE LENGTH OF NORMAL VECTOR
       SQ=SQRT(DELXA**2+DELYA**2+DELZB**2)
C********** CALCULATE DIRECTIONAL COSINES OF NORMAL VECTOR.
       ALN=DELXA/SQ
       BEN=DELYA/SQ
       GAN=DELZB/SQ
C********** CHECK DIRECTIONAL COSINES.
       CALL CHECK(6HELLNOR,ALN,BEN,GAN)
       CALL DEBUG(6HELLNOR)
       RETURN
       END
      SUBROUTINE ELLNOR(K)
C***********************************************************************
C********* ELLNOR CALCULATES DIRECTIONAL COSINES OF NORMAL
C********* TO A POINT ON AN ELLIPSOID OF REVOLUTION.
C***********************************************************************
      COMMON /69/         ABCO(20,200)      ,ALRAY(500)       ,BERAY(500)
     1 ,COORDS(6,50)     ,E(40,200)         ,EBASE(200)       ,ESOM(20,200)
     2 ,GARAY(500)       ,RED(20,200)       ,TITLE(12)        ,VMAT(20)
     3 ,VOL(200)         ,XLAM(200)         ,XRAY(500)        ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/    ALK(200)           ,ALPHA(40)        ,BEK(200)
     1 ,BETA(40)         ,DEV(200)          ,DK(200)          ,EK(200)
     2 ,FLAM(200)        ,ELAMAT(20)        ,EMAT(20)         ,ENERGY(200)
     3 ,GAK(200)         ,GAMMA(40)         ,REF(20)          ,SCRMAT(20)
     4 ,SUMRAY(200)      ,SUMSQR(200)       ,X(40)            ,XK(200)
     5 ,Y(40)            ,YK(200)           ,Z(40)            ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                        IFLAG(40)         ,IPOINT(50)       ,
     ,ISMAX(50)         ,ISOR(20)          ,JF(200)          ,JFL(200)         ,
     ,JL(200)           ,JM(200)           ,JN(200)          ,JP(200)          ,
     ,JRAY(200)         ,JSOR(50)          ,KBND(900)        ,KFLAG(200)       ,
     ,KP(200)           ,KTYP(200)         ,LAMP(50)         ,LANGLE(20)       ,
     ,LREFL(200)        ,LTYPE(20)         ,MAT(200)         ,MFL(20)          ,
     ,NMAT(20)          ,NUMRAY(200)
      COMMON/PARAMS/          AL           ,ALN         ,ALR         ,ALRF        ,RE     ,
     ,BEN          ,BER         ,BERF         ,DIS         ,DMIN        ,DZ          ,EPS    ,
     ,GA           ,GAN         ,GAR          ,GARF        ,PER         ,
     ,SUMRA        ,XI          ,XNOW         ,XOLD        ,XREF        ,XTRAN       ,YI     ,
     ,YNOW         ,YOLD        ,YREF         ,YTRAN       ,ZI          ,
     ,ZNOW         ,ZOLD        ,ZREF         ,ZTRAN
      COMMON/IPARAM/          FMAX          ,IMAX        ,INOW        ,
     ,IOPRAY       ,IOPRNT      ,IR           ,IRAY        ,JMAX        ,JNOW        ,JOLD   ,
     ,KINT         ,KMAX        ,KNOW         ,MMAX        ,NNOW        ,NSOR
      INTEGER F,FMAX
C********* CALCULATE X,Y,Z COMPONENTS OF NORMAL VECTOR.
      DELXA=(XNOW-XK(K))/DK(K)
      DELYA=(YNOW-YK(K))/DK(K)
      DELZB=(ZNOW-ZK(K)-EK(K))/EK(K)**2
C********* CALCULATE LENGTH OF NORMAL VECTOR
      SQ=SQRT(DELXA**2+DELYA**2+DELZB**2)
C********* CALCULATE DIRECTIONAL COSINES OF NORMAL VECTOR.
      ALN=DELXA/SQ
      BEN=DELYA/SQ
      GAN=DELZB/SQ
C********* CHECK DIRECTIONAL COSINES.
      CALL CHECK(6HELLNOR,ALN,BEN,GAN)
      CALL DEBUG(6HELLNOR)
      RETURN
      END
      SUBROUTINE ERPRNT(RES)
C*********************************************************************
C********** SUBROUTINE ERPRNT PRINTS SUBROUTINE NAME WHERE ERROR OCCURRED
C*********************************************************************
      COMMON /49/     ASCD(20,200)      ,ALRAY(500)        ,BERAY(500)
     1 ,COEFFS(6,50)  ,E(40,200)        ,EBASE(200)        ,ESCH(20,200)
     2 ,GARAY(500)    ,RED(20,200)      ,TITLE(12)         ,VMAT(20)
     3 ,VOL(200)      ,XLAM(200)        ,XRAY(500)         ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/  ALK(200)         ,ALPHA(40)         ,BEK(200)
     1 ,BETA(40)      ,DEV(200)         ,DK(200)           ,EK(200)
     2 ,FLAM(200)     ,ELAMAT(20)       ,EMAT(20)          ,ENERGY(200)
     3 ,GAK(200)      ,GAMMA(40)        ,REF(20)           ,SGMAT(20)
     4 ,SUMRAY(200)   ,SUMSOR(200)      ,X(40)             ,XK(200)
     5 ,Y(40)         ,YK(200)          ,Z(40)             ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                    IFLAG(40)      ,IPOINT(50)     ,
     ,ISMAX(50)     ,ISOR(20)          ,JF(200)       ,JFL(200)       ,
     ,JL(200)       ,JM(200)           ,JN(200)       ,JP(200)        ,
     ,JRAY(200)     ,JSOR(50)          ,KBND(900)     ,KFLAG(200)     ,
     ,KP(200)       ,KTYP(200)         ,LAMP(50)      ,LANGLE(20)     ,
     ,LABEL(200)    ,LTYPE(20)         ,MAT(200)      ,MFL(20)        ,
     ,NMAT(20)      ,NUMBLK(200)
      COMMON/PARAMS/     AL        ,ALN       ,ALR       ,ALRF      ,BE      ,
     ,BEN      ,BER      ,BERF      ,DIS       ,DMIN      ,DZ        ,EPS     ,
     ,GA       ,GAN      ,GAR       ,GANF      ,PER       ,
     ,SUMRA    ,X1       ,XNOW      ,XCLD      ,XREF      ,XTRAN     ,Y1      ,
     ,YNOW     ,YOLD     ,YREF      ,YTRAN     ,Z1        ,
     ,ZNOW     ,ZOLD     ,ZREF      ,ZTRAN
      COMMON/IPARAM/     FMAT      ,IMAX      ,INOW      ,
     ,IOPRAY   ,IOPRNT   ,IR        ,IRAY      ,JMAX      ,JNOW      ,JOLD    ,
     ,KINT     ,KMAX     ,KNOW      ,MMAX      ,NNOW      ,NSOM
      INTEGER F,FMAX
C********** PRINT SUBROUTINE NAME WHERE ERROR OCCURRED.
      PRINT 10,RES
   10 FORMAT(1H1,13HERROR IN RES ,A6)
C********** PRINT VALUES OF COMMON VARIABLES.
      PRINT 11,JOLD,JNOW,INOW,IMAX,KNOW
   11 FORMAT(1H ,6H JOLD=,I12,6H JNOW=,I12,6H INOW=,I12,
     ,6H IMAX=,I12,6H KNOW=,I12)
      PRINT 12,AL,BE,GA,X1,Y1,Z1
   12 FORMAT(1H ,6H   AL=, E12.4,6H   BE=, E12.4,6H   GA=, E12.4,
     ,6H   X1=, E12.4,6H   Y1=, E12.4,6H   Z1=, E12.4)
      PRINT 13,ALR,BER,GAR,XREF,YREF,ZREF
   13 FORMAT(1H ,6H  ALR=, E12.4,6H  BER=, E12.4,6H  GAR=, E12.4,
     ,6H XREF=, E12.4,6H YREF=, E12.4,6H ZREF=, E12.4)
      PRINT 14,ALRF,BERF,GARF,XTRAN,YTRAN,ZTRAN
   14 FORMAT(1H ,6H ALRF=, E12.4,6H BERF=, E12.4,6H GARF=, E12.4,
     ,6H XTRAN, E12.4,6H YTRAN, E12.4,6H ZTRAN, E12.4)
      PRINT 15,ALN,BEN,GAN,XNOW,YNOW,ZNOW
   15 FORMAT(1H 6H  ALN=, E12.4,6H  BEN=, E12.4,6H  GAN=, E12.4,
     ,6H XNOW=, E12.4,6H YNOW=, E12.4,6H ZNOW=, E12.4)
      PRINT 16,DIS,DMIN,PER
   16 FORMAT(1H ,6H  DIS=, E12.4,6H DMIN=, E12.4,6H  PER=, E12.4)
C********** PRINT SEGMENT AND MATERIAL RESULTS.
      CALL EXIT
      STOP
      END
      SUBROUTINE FINDR
C*********************************************************************
C********* FINDR FINDS THE ROOT AFTER IT HAS BEEN ISOLATED.
C********* PART OF HELIX INTERSECTION CALCULATION.
C********************** **********************************************
      COMMON /69/       ABCO(20,200)      ,ALRAY(500)       ,BERAY(500)
     1 ,COORDS(6,50)   ,E(40,200)         ,EBASE(200)       ,ESOR(20,200)
     2 ,FARAY(500)     ,RED(20,200)       ,TITLE(12)        ,VMAT(20)
     3 ,VOL(200)       ,XLAM(200)         ,XRAY(500)        ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/  ALK(200)           ,ALPHA(40)        ,BEK(200)
     1 ,BETA(40)       ,DEV(200)          ,DK(200)          ,EK(200)
     2 ,FLAM(200)      ,ELAMAT(20)        ,EMAT(20)         ,ENERGY(200)
     3 ,GAM(200)       ,GAMMA(40)         ,REF(20)          ,SGRMAT(20)
     4 ,SUMRAY(200)    ,SUMSGR(200)       ,X(40)            ,XK(200)
     5 ,Y(40)          ,YK(200)           ,Z(40)            ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                  IFLAG(40)      ,IPOINT(50)      ,
     *ISMAX(50)       ,ISOR(20)      ,JF(200)        ,JFL(200)        ,
     *JL(200)         ,JM(200)       ,JN(200)        ,JP(200)         ,
     *JRAY(200)       ,JSOR(50)      ,KBND(900)      ,KFLAG(200)      ,
     *KP(200)         ,KTYP(200)     ,LAMP(50)       ,LANGLE(20)      ,
     *LREFL(200)      ,LTYPE(20)     ,MAT(200)       ,MFL(20)         ,
     *NMIT(20)        ,NUMRAY(200)
      COMMON/PARAMS/         AL          ,ALN        ,ALR        ,ALRF        ,RE        ,
     *BEN        ,BER        ,BERF       ,DIS        ,DMIN       ,DZ          ,EPS       ,
     *GA         ,GAM        ,GAR        ,GARF       ,PER        ,
     *SUMRA      ,XI         ,XNOW       ,XOLD       ,XREF       ,XTRAN       ,YI        ,
     *YNOW       ,YOLD       ,YREF       ,YTRAN      ,ZI         ,
     *ZNOW       ,ZOLD       ,ZREF       ,ZTRAN
      COMMON/IPARAM/         FMAX        ,IMAX       ,INOW       ,
     *ICPRAY     ,ICPRNT     ,IR         ,IRAY       ,JMAX       ,JNOW        ,JOLD      ,
     *KINT       ,KMAX       ,KNOW       ,MMAX       ,NNOW       ,NSOR
      INTEGER F,FMAX
      COMMON/HELCOM/A,ABAR,B,BI,BIP,BP,CAP,DELTH,DELX,DELY,DELZ,DHIT,
     *PSIZ,REV,RHO,STH,TH,THI,SGRKS,RKS,CSTH,SNTH,RCSTH,RSNTH,SSTH,
     *COSTAN,THZ,DTHZ
      ICFLAG=0
      IC=0
C********* SAVE STARTING VALUES.
      THA=TH
      B6=B
      B6P=BP
      TH7=THI
      B7=BI
      B7P=BIP
C********* SET BOUNDING VALUES.
  100 TH8=TH
      B8=B
      B8P=BP
C********* CALCULATE NEW ANGLE.
      TH=TH8-(B8-ABAR)/B8P
C********* IF NEW ANGLE NOT BETWEEN TH7 AND TH8, GO TO 102.
      IF((TH-TH8)*(TH-TH7))101,101,102
  102 TH=(TH7+TH8)/2.0
C********* CALCULATE NEW B AND BP.
  101 CALL BCALC
      R=(B-ABAR)/(B6-ABAR)
      IC=IC+1
C********* IF MORE THAN 100 ITERATIONS, PRINT AND RETURN.
      IF(IC-100)1[illegible],199,111
  111 PRINT 11,THT,TH,THB,B,BP,RR,BSP
   11 FORMAT(18H NO CONV IN FINDR,,1P7E12.4)
      CALL ERRPRNT(6HFINDR )
      GO TO 106
  109 CONTINUE
      IF(ICFLAG-1)112,104,112
C......... IF CONVERGED, TRY ONE MORE ITERATION AND RETURN.
  112 IF(ABS(R-ABAR)-ABAR*1.E-3)113,113,103
  113 ICFLAG=1
C......... CHOOSE BOUNDING ANGLE AND TRY AGAIN.
  103 IF(R)106,106,100
  106 THT=THB
      GO TO 100
C......... IF INTERSECTION DISTANCE IS NEGATIVE, DONT SAVE.
  104 IF(STH)108,108,107
C......... IF INTERSECTION DISTANCE BETTER THAN PREVIOUS VALUE, SAVE IT.
  107 DHIT=AMIN1(DHIT,STH)
  108 TH=THG
      B=RR
      BP=RRP
      RETURN
      END
      SUBROUTINE FUNREF(LL)
      COMMON /69/        ABCD(20,200)      ,ALRAY(500)      ,BERAY(500)
     1 ,COORDS(6,50)    ,E(40,200)         ,EBASE(200)      ,ESOR(20,200)
     2 ,EARRAY(500)     ,RED(20,200)       ,TITLE(12)       ,VMAT(20)
     3 ,VOL(200)        ,XLAM(200)         ,XRAY(500)       ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/   ALK(200)           ,ALPHA(40)       ,BEK(200)
     1 ,BETA(40)        ,DEV(200)          ,DK(200)         ,EK(200)
     2 ,ELAM(200)       ,ELAMAT(20)        ,EMAT(20)        ,ENERGY(200)
     3 ,GAK(200)        ,GAMMA(40)         ,REF(20)         ,SCRRAY(20)
     4 ,SUMRAY(200)     ,SUMSQR(200)       ,X(40)           ,XK(200)
     5 ,Y(40)           ,YK(200)           ,Z(40)           ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                       IFLAG(40)        ,IPOINT(50)      ,
     ,ISMAX(50)        ,ISOR(20)           ,JF(200)         ,JFL(200)        ,
     ,JL(200)          ,JM(200)            ,JN(200)         ,JP(200)         ,
     ,JRAY(200)        ,JSCR(50)           ,KSNC(900)       ,KFLAG(200)      ,
     ,KP(200)          ,KTYP(200)          ,LAMP(50)        ,LANGLE(20)      ,
     ,LREFL(200)       ,LTYPE(20)          ,MAT(200)        ,MFL(20)         ,
     ,NMAT(20)         ,NUMRAY(200)
      COMMON/PARAMS/            AL       ,ALN      ,ALR      ,ALRF     ,RE     ,
     ,BEN      ,BER      ,BERF     ,DIS      ,DMIN     ,DZ       ,EPS    ,
     ,GA       ,GAN      ,GAR      ,GARF     ,PER      ,
     ,SUMRA    ,XI       ,XNOW     ,XOLD     ,XREF     ,XTRAN    ,YI     ,
     ,YNOW     ,YOLD     ,YREF     ,YTRAN    ,ZI       ,
     ,ZNOW     ,ZOLD     ,ZREF     ,ZTRAN
      COMMON/IPARAM/            FMAX     ,IMAX     ,INOW     ,
     ,ICRRAY   ,ICPRNT   ,IR       ,IRAY     ,JMAX     ,JNOW     ,JOLD   ,
     ,KINT     ,KMAX     ,KNOW     ,MMAX     ,MNOW     ,NSCR
      INTEGER F,FMAX
C********* FIND COSINE OF ANGLE OF INCIDENCE.
      COSTH=AL*ALN+BE*BEN+GA*GAN
      COSTH=COSTH**2
C********* CALCULATE PERCENT OF TRANSMISSION.
      PER=RED(LL,1)*(COSTH)
      RETURN
      END
      SUBROUTINE GEOPLT
C*********************************************************************
C********* GEOPLT GIVES PRINTER PLOTS  OF THE GEOMETRIC BOUNDARIES
C********* SLICED BY SELECTED PLANES.
C*********************************************************************
      COMMON /69/     ABCD(20,200)      ,ALRAY(500)       ,BERAY(500)
     1 ,CORNRS(6,50)  ,E(40,200)        ,EBASE(200)       ,ESOR(20,200)
     2 ,GARAY(500)    ,RED(20,200)      ,TITLE(12)        ,VMAT(20)
     3 ,VOL(200)      ,XLAM(200)        ,XRAY(500)        ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/  ALK(200)         ,ALPHA(40)        ,BEK(200)
     1 ,BETA(40)      ,DEV(200)         ,DK(200)          ,EK(200)
     2 ,ELAM(200)     ,ELAMAT(20)       ,EMAT(20)         ,ENERGY(200)
     3 ,GAK(200)      ,GAMMA(40)        ,REF(20)          ,SCRMAT(20)
     4 ,SUMRAY(200)   ,SUMSUM(200)      ,X(40)            ,XK(200)
     5 ,Y(40)         ,YK(200)          ,Z(40)            ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                  IFLAG(40)       ,IPOINT(50)      ,
     ,ISMAX(50)      ,ISOR(20)        ,JF(200)        ,JFL(200)        ,
     ,JL(200)        ,JM(200)         ,JN(200)        ,JP(200)         ,
     ,JRAY(200)      ,JSOR(50)        ,KEND(900)      ,KFLAG(200)      ,
     ,KP(200)        ,KTYP(200)       ,LAMP(50)       ,LANGLE(20)      ,
     ,LREFL(200)     ,LTYPE(20)       ,MAT(200)       ,MFL(20)         ,
     ,MMAT(20)       ,NUMRAY(200)
      COMMON/PARAMS/      AL        ,ALN        ,ALR        ,ALRF       ,RE     ,
     ,BEN       ,BER       ,BERF      ,DIS        ,DMIN       ,DZ         ,EPS    ,
     ,GA        ,GAN       ,GAR       ,GARF       ,PER        ,
     ,SUMRA     ,XI        ,XNOW      ,ACLD       ,XREF       ,XTRAN      ,YI     ,
     ,YNOW      ,YCLD      ,YREF      ,YTRAN      ,ZI         ,
     ,ZNOW      ,ZCLD      ,ZREF      ,ZTRAN
      COMMON/IPARAM/       FMAX      ,IMAX       ,INOW       ,
     ,ICPRAY    ,ICPRNT    ,IR        ,IRAY       ,JMAX       ,JNOW       ,JOLD   ,
     ,KINT      ,KMIN      ,KNOW      ,MMAX       ,MNOW       ,NSOR
      INTEGER F,FMAX
      DIMENSION LINE(130),ACOL(130),YCOL(130),ZCOL(130),DCOL(130),
     ,JCOL(130),ICHAR(34)
      DATA(NXX=130)
      DATA(ICHAR=1H , 1,1H2,1H3,1H4,1H5,1H6,1H7,1H8,1H9,1HA,
     ,1HB,1HC,1HD,1HE,1HF,1HG,1HH,1HJ,1HK,1HL,1HM,1HN,
     ,1HO,1HP,1HQ,1HR,1HS,1HT,1HU,1HV,1HW,1HX,1HY,1HZ)
C********* READ A CARD CONTAINING PLANE DEFINITION.
  123 READ 11,XZERO,YZERO,ZZERO,XONE,YONE,ZONE,XTWO,YTWO,ZTWO
   11 FORMAT(9E8.3)
      DELX=XONE-XZERO
      DELY=YONE-YZERO
      DELZ=ZONE-ZZERO
      XL=SQRT(DELX**2+DELY**2+DELZ**2)
C********* IF PLANE NOT DEFINED, THIS IS END OF PLOT DATA.
      IF(XL-1.E-10)121,121,122
C********* PRINT PLOT DATA.
  122 PRINT 12,XZERO,YZERO,ZZERO,XONE,YONE,ZONE,XTWO,YTWO,ZTWO
   12 FORMAT(1H1,40X,40HPLOT OF PLANE DEFINED BY POINTS P0 P1 P2//
     1  1X,34HP0 (LOWER LEFT CORNER OF PLOT) HAS,
     2  7X,35HP1 (LOWER RIGHT CORNER OF PLOT) HAS,
     3  6X,33HP2 (SOMEWHERE ALONG TOP LINE) HAS/
     4  3(3H X=,E10.3,3H Y=,E10.3,3H Z=,E10.3,2X)/)
C********* CALCULATE DIRECTIONAL COSINES OF HORIZONTAL RAYS.
      AXX=DELX/XL
      AXY=DELY/XL
      AXZ=DELZ/XL
      CN=AXX*(XTWO-XZERO)+AXY*(YTWO-YZERO)+AXZ*(ZTWO-ZZERO)
```

```
C********** CALCULATE COORDS OF UPPER LEFT CORNER OF PLOT AREA.
      XTOP=XTOP-CN*AXX
      YTOP=YTOP-CN*AXY
      ZTOP=ZTOP-CN*AXZ
      DELX=XTOP-XZERO
      DELY=YTOP-YZERO
      DELZ=ZTOP-ZZERO
      YL=SQRT(DELX**2+DELY**2+DELZ**2)
C********** CALCULATE DIRECTIONAL COSINES OF VERTICAL RAYS.
      AYX=DELX/YL
      AYY=DELY/YL
      AYZ=DELZ/YL
C********** CALCULATE RAY INTERVALS
      DSX=XL/(NX-1)
      DSY=1.66667*DSX
      NY=(YL/DSY+1.5)
      AL=-AYX
      BE=-AYY
      GA=-AYZ
      JNC=1
      DO 102 N=1,NX
C********** SET STARTING POINT FOR VERTICAL RAY NO. N.
      XCOL(N)=XTOP+AXX*(N-1)*DSX
      YCOL(N)=YTOP+AXY*(N-1)*DSX
      ZCOL(N)=ZTOP+AXZ*(N-1)*DSX
      XI=XCOL(N)
      YI=YCOL(N)
      ZI=ZCOL(N)
C********** FIND SEGMENT CONTAINING STARTING POINT.
      CALL SEGMNT
      IF(JNC)110,110,101
C********** FIND FIRST BOUNDARY INTERSECTION
  101 CALL BOUND
C********** STORE SEGMENT NUMBER AND DISTANCE TO INTERSECTION.
      JCOL(N)=JNC
      DCOL(N)=DMIN
      DO 103 K=1,KMAX
      KFLAG(K)=0
  103 CONTINUE
  102 CONTINUE
      NYM=NY-1
C********** DO ALL HORIZONTAL RAYS.
      DO 104 I=1,NYM
      N1=0
C********** SET STARTING POINT OF RAY.
      XI=XTOP-(I-.5)*DSY*AYX
      YI=YTOP-(I-.5)*DSY*AYY
      ZI=ZTOP-(I-.5)*DSY*AYZ
      AL=AXX
      BE=AXY
      GA=AXZ
      DL=0.0
      JNC=1
C********** FIND SEGMENT CONTAINING POINT.
  113 CALL SEGMNT
      IF(JNC)110,110,105
C********** FIND BOUNDARY INTERSECTION.
  105 CALL BOUND
      DO 106 K=1,KMAX
      KFLAG(K)=0
  106 CONTINUE
C********** SET PRINT CHARACTER FOR MATERIAL NUMBER.
```

```
      M=MOD(MAT(JNCM)-1,34)+1
      MPRT=ICHAR(M)
      DL=DL+DMIN
C********** IF DISTANCE TRAVELED GREATER THAN LENGTH OF RECTANGLE,
C********** GO TO 108.
      IF(DL-XL)107,107,108
C********** CALCULATE PLOT COORDINATES.
  107 XBAR=AXX*(X1-XZERO)+AXY*(Y1-YZERO)+AXZ*(Z1-ZZERO)
      YBAR=AYX*(X1-XZERO)+AYY*(Y1-YZERO)+AYZ*(Z1-ZZERO)
C********** SET COLUMN NUMBER OF BOUNDARY INTERSECTION.
      N2=(XBAR/CS)+1.5)
C********** SET PRINT CHARACTER TO BLANK.
      LINE(N2)=1H
      NONEP=N1+1
      NTWOM=N2-1
      IF(NONEP-NTWOM)109,109,112
C********** STORE MATERIAL NUMBER IN ALL PRINT POSITIONS BETWEEN
C********** CONSECUTIVE INTERSECTIONS.
  109 DO 111 N=NONEP,NTWOM
      LINE(N)=MPRT
  111 CONTINUE
  112 N1=N2
C********** GO LOOK FOR NEXT INTERSECTION.
      GO TO 113
C********** STORE MATERIAL NUMBER FOR REMAINDER OF PRINT POSITIONS.
  108 NONEP=N1+1
      IF(NONEP-NX)114,114,116
  114 DO 115 N=NONEP,NX
      LINE(N)=MPRT
  115 CONTINUE
  116 AL=-AYX
      BE=-AYY
      GA=-AYZ
C********** LOOP THROUGH ALL VERTICAL RAYS.
      DO 117 N=1,NX
C********** MOVE RAY STARTING POINT BY ONE LINE WIDTH.
      XCOL(N)=XCOL(N)+AL*DSY
      YCOL(N)=YCOL(N)+BE*DSY
      ZCOL(N)=ZCOL(N)+GA*DSY
      DCOL(N)=DCOL(N)-DSY
C********** IF INTERSECTION WAS NOT CROSSED GO TO 117.
      IF(DCOL(N))118,117,117
  118 X1=XCOL(N)
      Y1=YCOL(N)
      Z1=ZCOL(N)
      JNCM=JCOL(N)
C********** FIND NEW SEGMENT NUMBER.
      CALL SEGMNT
      IF(JNCM)110,110,119
C********** FIND NEXT BOUNDARY INTERSECTION.
  119 CALL BOUND
      DO 120 K=1,KMAX
      KFLAG(K)=0
  120 CONTINUE
C********** SET BLANK FOR PRINT POSITION.
      LINE(N)=1H
      DCOL(N)=DMIN
  117 CONTINUE
C********** PRINT LINE
      PRINT 10,LINE
   10 FORMAT(1H ,130A1)
C********** GO DO NEXT HORIZONTAL RAY.

  104 CONTINUE
C********** GO LOOK AT NEXT DATA CARD.
      GO TO 123
  121 JNCM=1
      RETURN
  110 CALL ERPRNT(6HGEOPLT)
      STOP
      END
      SUBROUTINE HELNOR(K)
C*****************************************************************************
C********** HELNOR CALCULATES DIRECTIONAL COSINES FOR THE NORMAL TO
C********** A POINT ON THE SURFACE OF A HELIX.
C*****************************************************************************
      COMMON /69/       ABCO(20,200)      ,ALRAY(500)       ,BERAY(500)
     1 ,COORDS(6,50)    ,E(40,200)        ,EBASE(200)       ,ESCR(20,200)
     2 ,GARAY(500)      ,RED(20,200)      ,TITLE(12)        ,VMAT(20)
     3 ,VOL(200)        ,XLAM(200)        ,XRAY(500)        ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/   ALK(200)          ,ALPHA(40)        ,BEK(200)
     1 ,BETA(40)        ,DEV(200)         ,DK(200)          ,EK(200)
     2 ,ELAM(200)       ,ELAMAT(20)       ,EMAT(20)         ,ENERGY(200)
     3 ,GAK(200)        ,GAMMA(40)        ,REF(20)          ,SUMMAT(20)
     4 ,SUMRAY(200)     ,SUMSQR(200)      ,X(40)            ,XK(200)
     5 ,Y(40)           ,YK(200)          ,Z(40)            ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                      IFLAG(40)        ,IPOINT(50)      ,
     *ISMAX(50)      ,ISOR(20)          ,JF(200)         ,JFL(200)        ,
     *JL(200)        ,JM(200)           ,JN(200)         ,JP(200)         ,
     *JRAY(200)      ,JSOR(50)          ,KBND(900)       ,KFLAG(200)      ,
     *KP(200)        ,KTYP(200)         ,LAMP(50)        ,LANGLE(20)      ,
     *LREFL(200)     ,LTYPE(20)         ,MAT(200)        ,MFL(20)         ,
     *NMAT(20)       ,NUMRAY(200)
      COMMON/PARAMS/          AL        ,ALN       ,ALR       ,ALRF      ,BE      ,
     *BEN       ,BER       ,BERF      ,DIS       ,DMIN      ,DZ        ,EPS     ,
     *GA        ,GAN       ,GAR       ,GARF      ,PER       ,
     *SUMRA     ,XI        ,XNOW      ,XCLD      ,XREF      ,XTRAN     ,YI      ,
     *YNOW      ,YOLD      ,YREF      ,YTRAN     ,ZI        ,
     *ZNOW      ,ZOLD      ,ZREF      ,ZTRAN
      COMMON/IPARAM/          FMAX      ,IMAX      ,INOW      ,
     *IOPRAY    ,IOPRNT    ,IR        ,IRAY      ,JMAX      ,JNOW      ,JOLD    ,
     *KINT      ,KMAX      ,KNOW      ,MMAX      ,NNOW      ,NSUR
      INTEGER F,FMAX
C********** FIND POINT ON HELICAL WIRE CLOSEST TO POINT ON SURFACE.
      CALL POINT(K,ALPT,BEPT,GAPT,XNOW,YNOW,ZNOW)
      R=SQRT(ALPT**2+BEPT**2+GAPT**2)
C********** CALCULATE DIRECTIONAL COSINES OF NORMAL.
      ALN=ALPT/R
      BEN=BEPT/R
      GAN=GAPT/R
      XNOW=XNOW-(R-DK(K))*ALN
      YNOW=YNOW-(R-DK(K))*BEN
      ZNOW=ZNOW-(R-DK(K))*GAN
      CALL CHECK(6HHELNOR,ALN,BEN,GAN)
      CALL DEBUG(6HHELNOR)
      RETURN
      END
      SUBROUTINE HYPNOR(K)
C*******************************************************************
C********** HYPNOR FINDS THE DIRECTIONAL COSINES OF THE NORMAL TO A
C********** POINT ON A HYPERBOLA OF REVOLUTION.
C*******************************************************************
       COMMON /69/        ABCD(20,200)      ,ALRAY(500)       ,BERAY(500)
     1 ,COORDS(6,50)    ,E(40,200)        ,EBASE(200)       ,ESOR(20,200)
     2 ,GARAY(500)      ,RED(20,200)      ,TITLE(12)        ,VMAT(20)
     3 ,VOL(200)        ,XLAM(200)        ,XRAY(500)        ,YRAY(500)
     4 ,ZRAY(500)
       COMMON /ARRAYS/  ALK(200)          ,ALPHA(40)        ,BEK(200)
     1 ,BETA(40)        ,DEV(200)         ,DK(200)          ,EK(200)
     2 ,ELAM(200)       ,ELAMAT(20)       ,EMAT(20)         ,ENERGY(200)
     3 ,GAK(200)        ,GAMMA(40)        ,REF(20)          ,SGRMAT(20)
     4 ,SUMRAY(200)     ,SUMSQR(200)      ,X(40)            ,XK(200)
     5 ,Y(40)           ,YK(200)          ,Z(40)            ,ZK(200)
     6 ,ZLAM(20)
       COMMON/IARRAY/                     IFLAG(40)        ,IPOINT(50)       ,
     ,ISMAX(50)       ,ISOR(20)          ,JF(200)         ,JFL(200)         ,
     ,JL(200)         ,JM(200)           ,JN(200)         ,JP(200)          ,
     ,JRAY(200)       ,JSCR(50)          ,KBND(900)       ,KFLAG(200)       ,
     ,KP(200)         ,KTYP(200)         ,LAMP(50)        ,LANGLE(20)       ,
     ,LREFL(200)      ,LTYPE(20)         ,MAT(200)        ,MFL(20)          ,
     ,NMAT(20)        ,NUMRAY(200)
       COMMON/PARAMS/            AL          ,ALN        ,ALR        ,ALRF        ,BE     ,
     ,BEN        ,BER        ,BERF        ,CIS        ,DMIN       ,DZ          ,EPS    ,
     ,GA         ,GAN        ,GAR         ,GAMF       ,PER        ,
     ,SUMRA      ,XI         ,XNOW        ,XOLD       ,XREF       ,XTRAN       ,YI     ,
     ,YNOW       ,YOLD       ,YREF        ,YTRAN      ,ZI         ,
     ,ZNOW       ,ZOLD       ,ZREF        ,ZTRAN      .
       COMMON/IPARAM/            FMAX        ,IMAX       ,INOW       ,
     ,IOPRAY     ,ICPRNT     ,IR          ,IRAY       ,JMAX       ,JNOW        ,JOLD   ,
     ,KINT       ,KMAX       ,KNOW        ,MMAX       ,NNOW       ,NSOR
       INTEGER F,FMAX
C********** CALCULATE COMPONENTS OF NORMAL VECTOR
      DELXA=(XNOW--XK(K))/DK(K)
      DELYA=(YNOW--YK(K))/DK(K)
      DELZB=(ZNOW--ZK(K)*EK(K))/(EK(K)**2)
C********** CALCULATE LENGTH OF NORMAL VECTOR.
      R=SQRT(DELXA**2+DELYA**2+DELZB**2)
C********** CALCULATE DIRECTIONAL COSINES OF NORMAL VECTOR.
      ALN=DELXA/R
      BEN=DELYA/R
      GAN=-DELZB/R
C********** CHECK COSINES
      CALL CHECK(6HHYPNOR,ALN,BEN,GAN)
      CALL DEBUG(6HHYPNOR)
      RETURN
      END
      SUBROUTINE INRAY
C**********************************************************************
C********** INRAY GETS THE NEXT NEW RAY.
C**********************************************************************
      COMMON /69/        ABCD(20,200)       ,ALRAY(500)         ,BERAY(500)
     1 ,COORDS(6,50)    ,E(40,200)         ,EBASE(200)         ,ESOR(20,200)
     2 ,GARAY(500)      ,RED(20,200)       ,TITLE(12)          ,XMAT(20)
     3 ,VOL(200)        ,XLAM(200)         ,XRAY(500)          ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/   ALK(200)           ,ALPHA(40)          ,BEK(200)
     1 ,BETA(40)        ,DEV(200)          ,DK(200)            ,EK(200)
     2 ,ELAM(200)       ,ELAMAT(20)        ,EMAT(20)           ,ENERGY(200)
     3 ,GAK(200)        ,GAMMA(40)         ,REF(20)            ,SORMAT(20)
     4 ,SUMRAY(200)     ,SUMSOR(200)       ,X(40)              ,XK(200)
     5 ,Y(40)           ,YK(200)           ,Z(40)              ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                    IFLAG(40)        ,IPOINT(50)       ,
     *ISMAX(50)       ,ISOR(20)        ,JF(200)         ,JFL(200)         ,
     *JL(200)         ,JM(200)         ,JN(200)         ,JP(200)          ,
     *JRAY(200)       ,JSOR(50)        ,KEND(900)       ,KFLAG(200)       ,
     *KP(200)         ,KTYP(200)       ,LAMP(50)        ,LANGLE(20)       ,
     *LPFFL(200)      ,LTYPE(20)       ,MAI(200)        ,MFL(20)          ,
     *MMAT(20)        ,NUMRAY(200)
      COMMON/PARAMS/           AL          ,ALN        ,ALR        ,ALRF       ,RE     ,
     *BEN        ,BER        ,BERF       ,DIS        ,DMIN       ,DZ         ,EPS    ,
     *GA         ,GAN        ,GAR        ,GARF       ,PER        ,
     *SUMRA      ,XI         ,XNOW       ,XOLD       ,XREF       ,XTRAN      ,YI     ,
     *YNOW       ,YOLD       ,YREF       ,YTRAN      ,ZI         ,
     *ZNOW       ,ZOLD       ,ZREF       ,ZTRAN
      COMMON/IPARAM/           FMAX        ,IMAX       ,INOW       ,
     *IOPRAY     ,IOPRNT     ,IR         ,IRAY       ,JMAX       ,JNOW       ,JOLD   ,
     *KINT       ,KMAX       ,KNOW       ,MMAX       ,NNOW       ,NSOR
      INTEGER F,FMAX
      COMMON/BASE/  FRAC      ,IDEBUG
      DATA (COUNT=0)
C********** COUNT NUMBER OF RAYS FROM SOURCE NUMBER NNOW.
      ICOUNT=ICOUNT+1
C********** IF ALL RAYS FOR SOURCE HAVE BEEN CREATED, GO TO NEXT SOURCE.
      IF(ICOUNT-ISMAX(NNOW))101,101,100
C********** GO TO NEXT SOURCE.
  100 NNOW=NNOW+1
      ICOUNT=1
      IF(NNOW-NSOR)101,101,110
  101 IF(ISMAX(NNOW))100,100,105
C********** INCREASE RAY INDEX.
  105 IMAX=IMAX+1
C********** GET LAMP NUMBER.
      LT=LAMP(NNOW)
C********** GET SOURCE TYPE.
      ISORR=ISOR(LT)
C********** BRANCH ON SOURCE TYPE.
      GO TO(103,200,200,400),ISORR
C********** GET RAY FROM VOLUME SOURCE.
  103 CALL VSORCE
      GO TO 104
C********** GET RAY FROM SURFACE SOURCE.
  200 CALL SSORCE
      GO TO 104
C********** GET RAY FROMINPUT TABLE.
  400 CALL RAYSOR(ICOUNT)
      GO TO 104
```

```
C********** STORE RAY ENERGY AND UPDATE TOTAL ENERGY AND RAY COUNT.
  104 DO 106 F=1,FMAX
      E(IMAX,F)=ESCR(LT,F)
      ERASE(F)=ESCR(LT,F)*FRAC
      IF(ERASE(F))107,107,108
  107 ERASE(F)=1.0
  108 SUMRA=SUMRA+E(IMAX,F)
  106 CONTINUE
      IFLAG(IMAX)=1
      IRAY=IRAY+1
C********** IF IOPRNT GREATER THAN 0, PRINT RAY PARAMETERS.
      IF(IOPRNT)110,110,141
  141 PRINT 10,IRAY,ALPHA(IMAX),BETA(IMAX),GAMMA(IMAX),
     *X(IMAX),Y(IMAX),Z(IMAX)
   10 FORMAT(1H,15HCREATED RAY NO.,I6/4H AL=, E12.4,4H BE=, E12.4,
     *4H GA=, E12.4,3H X=, E12.4,3H Y=, E12.4,3H Z=, E12.4)
  110 RETURN
      END
      FUNCTION INCN(K)
C*****************************************************************
C********** FUNCTION INCN DETERMINES IF POINT IS INSIDE A CONE.
C*****************************************************************
      COMMON /69/       ABCD(20,200)    ,ALRAY(500)       ,BERAY(500)
     1 ,COORDS(6,50)   ,E(40,200)       ,EBASE(200)       ,ESOR(20,200)
     2 ,GARAY(500)     ,RED(20,200)     ,TITLE(12)        ,VMAT(20)
     3 ,VOL(200)       ,XLAM(200)       ,XRAY(500)        ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/   ALK(200)        ,ALPHA(40)        ,BEK(200)
     1 ,BETA(40)       ,DEV(200)        ,DK(200)          ,EK(200)
     2 ,ELAM(200)      ,ELAMAT(20)      ,EMAT(20)         ,ENERGY(200)
     3 ,GAK(200)       ,GAMMA(40)       ,REF(20)          ,SCRMAT(20)
     4 ,SUMRAY(200)    ,SUMSQR(200)     ,X(40)            ,XK(200)
     5 ,Y(40)          ,YK(200)         ,Z(40)            ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                   IFLAG(40)       ,IPOINT(50)      ,
     ,ISMAX(50)     ,ISOR(20)        ,JF(200)         ,JFL(200)        ,
     ,JL(200)       ,JM(200)         ,JN(200)         ,JP(200)         ,
     ,JRAY(200)     ,JSOR(50)        ,KBND(900)       ,KFLAG(200)      ,
     ,KP(200)       ,KTYP(200)       ,LAMP(50)        ,LANGLE(20)      ,
     ,LREFL(200)    ,LTYPE(20)       ,MAT(200)        ,MFL(20)         ,
     ,NMAT(20)      ,NUMRAY(200)
      COMMON/PARAMS/         AL          ,ALN        ,ALR        ,ALRF       ,BE     ,
     ,BEN        ,BER        ,BERF       ,DIS        ,DMIN       ,DZ         ,EPS    ,
     ,GA         ,GAN        ,GAR        ,GARF       ,PER        ,
     ,SUMRA      ,XI         ,XNOW       ,XCLO       ,XREF       ,XTRAN      ,YI     ,
     ,YNOW       ,YOLD       ,YREF       ,YTRAN      ,ZI         ,
     ,ZNOW       ,ZOLD       ,ZREF       ,ZTRAN
      COMMON/IPARAM/         FMAX        ,IMAX       ,INOW       ,
     ,IOPRAY     ,IOPRNT     ,IR         ,IRAY       ,JMAX       ,JNOW       ,JOLC   ,
     ,KINT       ,KPRIT      ,KNOW       ,MMAX       ,NNOW       ,NSOR
      INTEGER F,FMAX
      DELZ=ZI-ZK(K)
C********** IF POINT ON WRONG SIDE OF VERTEX GO TO 101.
      IF(DELZ*EK(K))101,101,103
  103 DELX=XI-XK(K)
      DELY=YI-YK(K)
C********** PUT POINT INTO EQUATION OF CONE(FP).
      FP=(1.0-DK(K))*DELZ**2-DK(K)*(DELX**2+DELY**2)
C********** IF FP LESS THAN 0, POINT IS OUTSIDE CONE.
      IF(FP)101,102,102
C********** POINT IS INSIDE.
  102 INCN=1
      RETURN
C********** POINT IS OUTSIDE.
  101 INCN=-1
      RETURN
      END
      FUNCTION INCON(K)
C*********************************************************************
C********** FUNCTION INCON DETERMINES IF A POINT(XI,YI,ZI) IS INSIDE
C********** CONICAL BOUNDARY NUMBER K.
C********** INCON=+1 FOR YES.
C********** INCON=-1 FOR NO.
C*********************************************************************
      COMMON /69/       ABCO(20,200)    ,ALRAY(500)      ,BERAY(500)
     1 ,COORDS(6,50)  ,E(40,200)       ,EBASE(200)      ,ESCR(20,200)
     2 ,GARAY(500)    ,RED(20,200)     ,TITLE(12)       ,VMAT(20)
     3 ,VOL(200)      ,XLAM(200)       ,XRAY(500)       ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/  ALK(200)        ,ALPHA(40)       ,BEK(200)
     1 ,BETA(40)      ,DEV(200)        ,DK(200)         ,EK(200)
     2 ,ELAM(200)     ,ELAMAT(20)      ,EMAT(20)        ,ENERGY(200)
     3 ,GAK(200)      ,GAMMA(40)       ,REF(20)         ,SUMMAT(20)
     4 ,SUMRAY(200)   ,SUMSCR(200)     ,X(40)           ,XK(200)
     5 ,Y(40)         ,YK(200)         ,Z(40)           ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                  IFLAG(40)      ,IPOINT(50)     ,
     *ISMAX(50)      ,ISOR(20)        ,JF(200)       ,JFL(200)       ,
     *JL(200)        ,JM(200)         ,JN(200)       ,JP(200)        ,
     *JRAY(200)      ,JSCR(50)        ,KBND(900)     ,KFLAG(200)     ,
     *KP(200)        ,KTYP(200)       ,LAMP(50)      ,LANGLE(20)     ,
     *LREFL(200)     ,LTYPE(20)       ,MAT(200)      ,MFL(20)        ,
     *NMAT(20)       ,NUMRAY(200)
      COMMON/PARAMS/       AL          ,ALN        ,ALR        ,ALRF       ,BE     ,
     *BEN        ,BER        ,BERF        ,DIS        ,DMIN       ,DZ         ,EPS    ,
     *GA         ,GAN        ,GAR         ,GARF       ,PER        ,
     *SUMRA      ,XI         ,XNOW        ,XOLD       ,XREF       ,XTRAN      ,YI     ,
     *YNOW       ,YOLD       ,YREF        ,YTRAN      ,ZI         ,
     *ZNOW       ,ZOLD       ,ZREF        ,ZTRAN
      COMMON/IPARAM/       FMAX        ,IMAX       ,INOW       ,
     *IORRAY     ,ICPRNT     ,IR          ,IRAY       ,JMAX       ,JNOW       ,JOLD   ,
     *KINY       ,KMAX       ,KNOW        ,MMAX       ,MNOW       ,NSOR
      INTEGER F,FMAX
C********** CALCULATE DISTANCE FROM FOCUS TO POINT.
      DX=XI-XK(K)
      DY=YI-YK(K)
      RR=SQRT(DX**2+DY**2)
      IF(RR-1.E-6)102,102,100
C********** FIND COSINES OF VECTOR FROM FOCUS TO POINT.
  100 ALL=DX/RR
      BEL=DY/RR
      CALL CHECK(5H INCON,ALL,BEL,0,0)
      DEN=1.0-EK(K)*(ALL*ALK(K)+BEL*BEK(K))
      IF(ABS(DEN)-1.E-6)102,102,101
C********** FIND DISTANCE FROM FOCUS TO SURFACE.
  101 RAD=(DK(K)*EK(K))/DEN
      IF(RR-RAD)102,102,103
C********** POINT IS INSIDE CONIC.
  102 INCON=1
      GO TO 104
C********** POINT IS OUTSIDE CONIC.
  103 INCON=-1
  104 CONTINUE
      RETURN
      END
      FUNCTION INCYL(K)
C**********************************************************************
C********* FUNCTION INCYL DETERMINES IF A POINT(XI,YI,ZI) IS INSIDE
C********* CYLINDRICAL BOUNDARY NUMBER K.
C********* INCYL=+1 FOR YES.
C********* INCYL=-1 FOR NO.
C**********************************************************************
      COMMON /69/      ABC(20,200)     ,ALRAY(500)     ,BERAY(500)
     1 ,COORDS(6,50)  ,E(40,200)      ,EBASE(200)     ,ESCR(20,200)
     2 ,GARAY(500)    ,RED(20,200)    ,TITLE(12)      ,VMAT(20)
     3 ,VOL(200)      ,XLAM(200)      ,XRAY(500)      ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/  ALK(200)        ,ALPHA(40)      ,BEK(200)
     1 ,BETA(40)      ,DEV(200)       ,DK(200)        ,EK(200)
     2 ,FLAM(200)     ,ELAMAT(20)     ,EMAT(20)       ,ENERGY(200)
     3 ,GAK(200)      ,GAMMA(40)      ,REF(20)        ,SCRMAT(20)
     4 ,SUMRAY(200)   ,SUMSQR(200)    ,X(40)          ,XK(200)
     5 ,Y(40)         ,YK(200)        ,Z(40)          ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                   IFLAG(40)      ,IPOINT(50)     ,
     ,ISMAX(50)     ,ISOR(20)       ,JF(200)        ,JFL(200)       ,
     ,JL(200)       ,JM(200)        ,JP(200)        ,JP(200)        ,
     ,JRAY(200)     ,JSOR(50)       ,KBND(900)      ,KFLAG(200)     ,
     ,KP(200)       ,KTYP(200)      ,LAMP(50)       ,LANGLE(20)     ,
     ,LRFFL(200)    ,LTYPE(20)      ,MAT(200)       ,MFL(20)        ,
     ,NMAT(20)      ,NUMRAY(200)
      COMMON/PARAMS/           AL          ,ALM         ,ALR        ,ALRF       ,BE         ,
     ,BEN       ,BER        ,BERF       ,DIS         ,DMIN       ,DZ         ,EPS        ,
     ,GA        ,GAN        ,GAR        ,GARF        ,PER        ,
     ,SUMRA     ,XI         ,XNOW       ,XOLD        ,XREF       ,XTRAN      ,YI         ,
     ,YNOW      ,YOLD       ,YREF       ,YTRAN       ,ZI         ,
     ,ZNOW      ,ZOLD       ,ZREF       ,ZTRAN
      COMMON/IPARAM/           FMAX        ,IMAX        ,INOW       ,
     ,IOFRAY    ,IOPRNT     ,IR         ,IRAY        ,JMAX       ,JNOW       ,JOLD       ,
     ,KINT      ,KMAX       ,KNOW       ,MMAX        ,MNOW       ,NSCR
      INTEGER F,FMAX
C********* FIND DISTANCE FROM             CYLINDRICAL AXIS TO POINT.
      DX=XI-XK(K)
      DY=YI-YK(K)
      ZD=ZI-ZK(K)
      DD=DX**2+DY**2+ZD**2-(ALK(K)*DX+BEK(K)*DY+GAK(K)*ZD)**2
C********* IS DISTANCE LESS THAN RADIUS<<
      IF(DD-DK(K)**2)101,10[illegible],102
C********* POINT IS INSIDE CYLINDER.
  101 INCYL =1
      RETURN
C********* POINT IS OUTSIDE CYLINDER.
  102 INCYL=-1
      RETURN
      END
      FUNCTION INELL(K)
C*********************************************************************
C********** FUNCTION INELL FINDS IF POINT IS INSIDE ELLIPSOID.
C*********************************************************************
      COMMON /69/      ABCO(20,200)     ,ALRAY(500)      ,BERAY(500)
     1 ,COORDS(6,50)  ,E(40,200)        ,EBASE(200)      ,ESOR(20,200)
     2 ,GARAY(500)    ,REC(20,200)      ,TITLE(12)       ,VMAT(20)
     3 ,VOL(200)      ,XLAM(200)        ,XRAY(500)       ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/  ALK(200)         ,ALPHA(40)       ,BEK(200)
     1 ,BETA(40)      ,DEV(200)         ,DK(200)         ,EK(200)
     2 ,ELAM(200)     ,ELAMAT(20)       ,EMAT(20)        ,ENERGY(200)
     3 ,GAK(200)      ,GAMMA(40)        ,REF(20)         ,SGMAT(20)
     4 ,SUMRAY(200)   ,SUMSOR(200)      ,X(40)           ,XK(200)
     5 ,Y(40)         ,YK(200)          ,Z(40)           ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                    IFLAG(40)     ,IPOINT(50)     ,
     *,ISMAX(50)    ,ISOR(20)         ,JF(200)       ,JFL(200)       ,
     *,JL(200)      ,JM(200)          ,JN(200)       ,JP(200)        ,
     *,JRAY(200)    ,JSOR(50)         ,KBND(900)     ,KFLAG(200)     ,
     *,KP(200)      ,KTYP(200)        ,LAMP(50)      ,LANGLE(20)     ,
     *,LREFL(200)   ,LTYPE(20)        ,MAT(200)      ,MFL(20)        ,
     *,NMAT(20)     ,NUMRAY(200)
      COMMON/PARAMS/       AL         ,ALN       ,ALR       ,ALRF      ,BE    ,
     *,BEN     ,BER      ,BERF       ,DIS       ,DMIN      ,DZ        ,EPS   ,
     *,GA      ,GAN      ,GAR        ,GARF      ,PER       ,
     *,SUMGA   ,XI       ,XNOW       ,XOLD      ,XREF      ,XTRAN     ,YI    ,
     *,YNOW    ,YOLD     ,YREF       ,YTRAN     ,ZI        ,
     *,ZNOW    ,ZOLD     ,ZREF       ,ZTRAN
      COMMON/IPARAM/       FMAX       ,IMAX      ,INOW      ,
     *,IOPRAY  ,IOPRNT   ,IR         ,IRAY      ,JMAX      ,JNOW      ,JOLD  ,
     *,KINT    ,KMAX     ,KNOW       ,MMAX      ,MNOW      ,NSCR
      INTEGER F,FMAX
C********** CALCULATE FUNCTION FP.
      FP=1.0-((XI-XK(K))**2+(YI-YK(K))**2)/DK(K)
     *-((ZI-ZK(K)-EK(K))/EK(K))**2
C********** IF FP LESS THAN 0, POINT IS OUTSIDE
      IF(FP)102,101,101
C********** POINT INSIDE
  101 INELL=1
      RETURN
C********** POINT OUTSIDE
  102 INELL=-1
      RETURN
      END
      SUBROUTINE INFL(IFL)
C*****************************************************************************
C********** INFL LOOKS FOR AN INFLECTION POINT.
C********** PART OF HELIX INTERSECTION CALCULATION.
C*****************************************************************************
      COMMON /69/       ABCO(20,200)       ,ALRAY(500)       ,BERAY(500)
     1 ,COORDS(6,50)   ,E(40,200)          ,EBASE(200)       ,ESOR(20,[illegible])
     2 ,GARAY(500)     ,RED(20,200)        ,TITLE(12)        ,VMAT(20)
     3 ,VOL(200)       ,XLAM(200)          ,XRAY(500)        ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/   ALK(200)           ,ALPHA(40)        ,BEK(200)
     1 ,BETA(40)       ,DEV(200)           ,DK(200)          ,EK(200)
     2 ,ELAM(200)      ,ELAMAT(20)         ,EMAT(20)         ,ENERGY(200)
     3 ,GAK(200)       ,GAMMA(40)          ,REF(20)          ,SORMAT(20)
     4 ,SUMRAY(200)    ,SUMSQR(200)        ,X(40)            ,XK(200)
     5 ,Y(40)          ,YK(200)            ,Z(40)            ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                    IFLAG(40)      ,IPOINT(50)       ,
     ,ISMAX(50)      ,ISOR(20)        ,JF(200)        ,JFL(200)         ,
     ,JL(200)        ,JM(200)         ,JN(200)        ,JP(200)          ,
     ,JRAY(200)      ,JSOR(50)        ,KBND(900)      ,KFLAG(200)       ,
     ,KP(200)        ,KTYP(200)       ,LAMP(50)       ,LANGLE(20)       ,
     ,LREFL(200)     ,LTYPE(20)       ,MAT(200)       ,MFL(20)          ,
     ,NMAT(20)       ,NUMRAY(200)
      COMMON/PARAMS/          AL         ,ALN        ,ALR        ,ALRF       ,RE      ,
     ,BEN        ,BER        ,BERF       ,DIS        ,DMIN       ,DZ         ,EPS     ,
     ,GA         ,GAN        ,GAR        ,GARF       ,PER        ,
     ,SUMRA      ,XI         ,XNOW       ,XOLD       ,XREF       ,XTRAN      ,YI      ,
     ,YNOW       ,YOLD       ,YREF       ,YTRAN      ,ZI         ,
     ,ZNOW       ,ZOLD       ,ZREF       ,ZTRAN
      COMMON/IPARAM/          FMAX       ,IMAX       ,INOW       ,
     ,IOPRAY     ,IOPRNT     ,IR         ,IRAY       ,JMAX       ,JNOW       ,JOLD    ,
     ,KINT       ,KMAX       ,KNOW       ,MMAX       ,NNOW       ,NSOR
      INTEGER F,FMAX
      COMMON/HELCOM/A,ABAR,B,B1,B1P,BP,CAP,DELTH,DELX,DELY,DELZ,[illegible]IT,
     ,PSI7,REV,RHO,STH,TH,TH1,SQRKS,RKS,CSTH,SNTH,RCSTH,RSNTH,BS[illegible],
     ,COSTAN,THZ,DTHZ
      IFL=0
C********** IF FUNCTION LOOKS LIKE A PARABOLA, GO TO 102.
      IF((B-B1)/((BP*B1P)*(TH-TH1))-.25)101,102,102
C********** IF ROOT IS BRACKETED, FIND ROOT.
  102 IF((B-ABAR)*(B1-ABAR))103,103,110
  103 CALL FINDR
      GO TO 110
C********** SAVE STARTING VALUES.
  101 TH2=TH
      B2=B
      B2P=BP
      TH3=TH1
      B3=B1
      B3P=B1P
C********** CALCULATE NEW ANGLE
  104 TH=(TH+TH1)/2.0
C********** CALCULATE NEW B AND BP.
      CALL BCALC
C********** IF SIGN REVERSAL, CALL REVS TWICE.
      IF(B1P*BP)105,105,106
  105 CALL REVS
      IFL=1
      TH1=TH
      B1=B
      B1P=AP
      TM=TM2
      B=A2
      B2=A2P
      CALL REVS
      GO TO 110
C.......... IF FUNCTION LOOKS LIKE A PARABOLA, GO TO 107.
  106 IF((B-B1)/((B2+B1P)*(TM-TM1))-.25)104,107,107
C.......... IF ROOT IS BRACKETED, FIND ROOT
  107 IF((B-ABAR)*(B1-ABAR))108,108,109
  108 CALL FIXDR
C.......... SET LIMITS FOR OTHER PART OF FUNCTION.
  109 TM1=TM
      B1=B
      B1P=BP
      TM=TM2
      B=A2
      B2=A2P
C.......... IF FUNCTION LOOKS LIKE PARABOLA, GO TO 111.
      IF((B-B1)/((B2+B1P)*(TM-TM1))-.25)104,111,111
C.......... IF ROOT IS BRACKETED, FIND ROOT.
  111 IF((B-ABAR)*(B1-ABAR))112,112,110
  112 CALL FIXDR
  110 RETURN
      END
      FUNCTION INHEL(K)
C**********************************************************************
C********* INHEL DETERMINES IF POINT XI,YI,ZI IS INSIDE HELIX.
C**********************************************************************
      COMMON /A9/        ABCD(20,200)    ,ALRAY(500)     ,BERAY(500)
     1 ,COORDS(  ,50)   ,E(40,200)      ,EBASE(200)     ,ESCM(20,200)
     2 ,GARAY(500)      ,RED(20,200)    ,TITLE(12)      ,VMAT(20)
     3 ,VOL(200)        ,XLAM(200)      ,XRAY(500)      ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/    ALK(200)        ,ALPHA(40)      ,BEK(200)
     1 ,BETA(40)        ,DEV(200)       ,DK(200)        ,EK(200)
     2 ,ELAM(200)       ,ELAMAT(20)     ,EMAT(20)       ,ENERGY(200)
     3 ,GAK(200)        ,GAMMA(40)      ,REF(20)        ,SCRMAT(20)
     4 ,SUMRAY(200)     ,SUMSQR(200)    ,X(40)          ,XK(200)
     5 ,Y(40)           ,YK(200)        ,Z(40)          ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                     IFLAG(40)      ,IPOINT(50)     ,
     ,ISMAX(50)     ,ISCR(20)       ,JF(200)        ,JFL(200)       ,
     ,JL(200)       ,JM(200)        ,JN(200)        ,JP(200)        ,
     ,JRAY(200)     ,JSCR(50)       ,KGRD(900)      ,KFLAG(200)     ,
     ,KP(200)       ,KTYP(200)      ,LAMP(50)       ,LANGLE(20)     ,
     ,LREFL(200)    ,LTYPE(20)      ,MAT(200)       ,MFL(20)        ,
     ,NMAT(20)      ,NUMRAY(200)
      COMMON/PARAMS/          AL          ,ALN        ,ALR        ,ALRF       ,RE        ,
     ,BEK       ,BER         ,BERF        ,DIS        ,DMIN       ,DZ         ,EPS       ,
     ,GA        ,GAM         ,GAR         ,GARF       ,PER        ,
     ,SUMRA     ,XI          ,XNOW        ,XOLD       ,XREF       ,XTRAN      ,YI        ,
     ,YNOW      ,YOLD        ,YREF        ,YTRAN      ,ZI         ,
     ,ZNOW      ,ZOLD        ,ZREF        ,ZTRAN
      COMMON/IPARAM/          FMAX        ,IMAX       ,INOW       ,
     ,ICPRAY    ,ICPRNT      ,IR          ,IRAY       ,JMAX       ,JNOW       ,JOLD      ,
     ,KINT      ,KMAX        ,KNOW        ,MMAX       ,NNOW       ,NSQR
      INTEGER F,FMAX
      DELX=XI-XK(K)
      DELY=YI-YK(K)
C********* CALCULATE DISTANCE FROM AXIS TO POINT.
      R=DELX**2+DELY**2
      RIN=(BEK(K)-DK(K))**2
      ROUT=(BEK(K)+DK(K))**2
C********* IF POINT NOT BETWEEN INNER AND OUTER RADIUS, GO TO 102.
      IF(R-RIN)102,103,103
  103 IF(R-ROUT)104,104,102
  104 CONTINUE
C********* LOCATE NEAREST POINT ON HELICAL WIRE.
      CALL POINT(K,ALPT,BEPT,GAPT,XI,YI,ZI)
C********* CALCULATE DISTANCE SQUARED BETWEEN TWO POINTS.
      DS=ALPT**2+BEPT**2+GAPT**2
C********* IF DISTANCE SQUARED LESS THAN TUBE RADIUS SQUARED, GO TO 101.
      IF(DS-DK(K)**2)101,101,102
C********* POINT IS INSIDE
  101 INHEL=1
      RETURN
C********* POINT IS OUTSIDE
  102 INHEL=-1
      RETURN
      END
      FUNCTION INHYP(K)
C**************************************************** ************
C********* FUNCTION INHYP FINDS IF POINT IS INSIDE HYPERBOLOID.
C*****************************************************************
      COMMON /69/       ABCO(20,200)      ,ALRAY(500)       ,BERAY(500)
     1 ,COORDS(6,50)   ,E(40,200)        ,ESASE(200)       ,ESOR(20,200)
     2 ,GARAY(500)     ,RED(20,200)      ,TITLE(12)        ,VMAT(20)
     3 ,VCL(200)       ,XLAM(200)        ,XRAY(500)        ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/  ALK(200)          ,ALPHA(40)        ,BEK(200)
     1 ,BETA(40)       ,DEV(200)         ,DK(200)          ,EK(200)
     2 ,FLAM(200)      ,ELAMAT(20)       ,EMAT(20)         ,ENERGY(200)
     3 ,GAK(200)       ,GAMMA(40)        ,REF(20)          ,SCRMAT(20)
     4 ,SUMRAY(200)    ,SUMSQR(200)      ,X(40)            ,XK(200)
     5 ,Y(40)          ,YK(200)          ,Z(40)            ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                  IFLAG(40)        ,IPOINT(50)      ,
     *ISMAX(50)       ,ISOR(20)       ,JF(200)         ,JFL(200)        ,
     *JL(200)         ,JM(200)        ,JN(200)         ,JP(200)         ,
     *JRAY(200)       ,JSOR(50)       ,KBND(900)       ,KFLAG(200)      ,
     *KP(200)         ,KTYP(200)      ,LAMP(50)        ,LANGLE(20)      ,
     *LREFL(200)      ,LTYPE(20)      ,MAT(200)        ,MFL(20)         ,
     *NMAT(20)        ,NUMRAY(200)
      COMMON/PARAMS/        AL          ,ALN        ,ALR        ,ALRF       ,RE     ,
     *BEN        ,BER        ,BERF       ,DIS        ,DMIN       ,DZ         ,EPS    ,
     *GA         ,GAN        ,GAR        ,GARF       ,PER        ,
     *SUMRA      ,XI         ,XNOW       ,XOLD       ,XREF       ,XTRAN      ,YI     ,
     *YNOW       ,YOLD       ,YREF       ,YTRAN      ,ZI         ,
     *ZNOW       ,ZOLD       ,ZREF       ,ZTRAN
      COMMON/IPARAM/        FMAX        ,IMAX       ,INOW       ,
     *IOPRAY     ,IOPRNT     ,IR         ,IRAY       ,JMAX       ,JNOW       ,JOLD   ,
     *KINT       ,KMAX       ,KNOW       ,MMAX       ,MNOW       ,NSOR
      INTEGER F,FMAX
C********* CALCULATE FUNCTION FP.
      DELZ=ZI-ZK(K)
      IF(DELZ*GAK(K))102,102,103
  103 DELX=XI-XK(K)
      DELY=YI-YK(K)
      FP=-1.0-(DELX**2+DELY**2)/DK(K)+((DELZ+EK(K))**2)/(EK(K)**2)
C********* IF FP LESS THAN 0, POINT IS OUTSIDE.
      IF(FP)102,101,101
C********* POINT INSIDE
  101 INHYP=1
      RETURN
C********* POINT OUTSIDE
  102 INHYP=-1
      RETURN
      END
      FUNCTION INPAR(K)
C*********************************************************************
C********** FUNCTION INPAR FINDS IF POINT IS INSIDE PARABOLOID.
C*********************************************************************
      COMMON /69/      ABCO(20,200)     ,ALRAY(500)      ,BERAY(500)
     1 ,COORDS(6,50)   ,E(40,200)        ,EBASE(200)      ,ESCR(20,200)
     2 ,FARAY(500)     ,RED(20,200)      ,TITLE(12)       ,VMAT(20)
     3 ,VOL(200)       ,XLAM(200)        ,XRAY(500)       ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/  ALK(200)          ,ALPHA(40)       ,BEK(200)
     1 ,BETA(40)       ,DEV(200)         ,DK(200)         ,EK(200)
     2 ,ELAM(200)      ,ELAMAT(20)       ,EMAT(20)        ,ENERGY(200)
     3 ,GAK(200)       ,GAMMA(40)        ,REF(20)         ,SCRMAT(20)
     4 ,SUMRAY(200)    ,SUMSQR(200)      ,X(40)           ,XK(200)
     5 ,Y(40)          ,YK(200)          ,Z(40)           ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                 IFLAG(40)       ,IPOINT(50)      ,
     ,ISMAX(50),      ,ISOR(20)      ,JF(200)        ,JFL(200)        ,
     ,JL(200)         ,JM(200)       ,JN(200)        ,JP(200)         ,
     ,JRAY(200)       ,JSOR(50)      ,KBND(900)      ,KFLAG(200)      ,
     ,KP(200)         ,KTYP(200)     ,LAMP(50)       ,LANGLE(20)      ,
     ,LREFL(200)      ,LTYPE(20)     ,MAT(200)       ,MFL(20)         ,
     ,NMAT(20)        ,NUMRAY(200)
      COMMON/PARAMS/          AL         ,ALN        ,ALR        ,ALRF        ,BE      ,
     ,BEN       ,BER       ,BERF       ,DIS        ,DMIN       ,DZ          ,EPS     ,
     ,GA        ,GAN       ,GAR        ,GANF       ,PER        ,
     ,SUMRA     ,XI        ,XNOW       ,XOLD       ,XREF       ,XTRAN       ,YI      ,
     ,YNOW      ,YOLD      ,YREF       ,YTRAN      ,ZI         ,
     ,ZNOW      ,ZOLD      ,ZREF       ,ZTRAN
      COMMON/IPARAM/          FMAX       ,IMAX       ,INOW       ,
     ,IOFRAY    ,ICPRNT    ,IR         ,IRAY       ,JMAX       ,JNOW        ,JOLD    ,
     ,KINT      ,KMAX      ,KNOW       ,MMAX       ,NNOW       ,NSOR
      INTEGER F,FMAX
C********** CALCULATE FUNCTION FP.
      FP=4.0*DK(K)*(ZI-ZK(K))-(XI-XK(K))**2-(YI-YK(K))**2
C********** IF FP LESS THAN 0. POINT IS OUTSIDE
      IF(FP)101,102,102
C********** POINT IS INSIDE.
  102 INPAR=1
      RETURN
C********** POINT IS OUTSIDE.
  101 INPAR=-1
      RETURN
      END
      FUNCTION INPLAN(K)
C******************************************************************
C********** FUNCTION INPLAN DETERMINES IF A POINT(XI,YI,ZI) IS ON
C********** THE ORIGIN SIDE OF PLANE BOUNDARY NUMBER K.
C********** INPLAN=+1 FOR YES.
C********** INPLAN=-1 FOR NO.
C******************************************************************
      COMMON /69/        ABCO(20,200)      ,ALRAY(500)       ,BERAY(500)
     1 ,COORDS(6,50)  ,E(40,200)        ,EBASE(200)       ,ESOR(20,200)
     2 ,GARAY(500)    ,RED(20,200)      ,TITLE(12)        ,VMAT(20)
     3 ,VOL(200)      ,XLAM(200)        ,XRAY(500)        ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/  ALK(200)         ,ALPHA(40)        ,BEK(200)
     1 ,BETA(40)      ,DEV(200)         ,DK(200)          ,EK(200)
     2 ,ELAM(200)     ,ELAMAT(20)       ,EMAT(20)         ,ENERGY(200)
     3 ,GAK(200)      ,GAMMA(40)        ,REF(20)          ,SORMAT(20)
     4 ,SUMRAY(200)   ,SUMSOR(200)      ,X(40)            ,XK(200)
     5 ,Y(40)         ,YK(200)          ,Z(40)            ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                   IFLAG(40)        ,IPOINI(50)       ,
     ,ISMAX(50)      ,ISOR(20)        ,JF(200)         ,JFL(200)         ,
     ,JL(200)        ,JM(200)         ,JN(200)         ,JP(200)          ,
     ,JREL(200)      ,JSOR(50)        ,KBND(900)       ,KFLAG(200)       ,
     ,KP(200)        ,KTYP(200)       ,LAMP(50)        ,LANGLE(20)       ,
     ,LABEL(200)     ,LTYPE(20)       ,MAT(200)        ,MFL(20)          ,
     ,NMAT(20)       ,NUMRAY(200)
      COMMON/PARAMS/          AL        ,ALN       ,ALR       ,ALRF      ,RE      ,
     ,BEN       ,BER       ,BERF      ,DIS       ,DMIN      ,DZ        ,EPS     ,
     ,GA        ,GAN       ,GAR       ,GANF      ,PER       ,
     ,SUMRA     ,XI        ,XNOW      ,XOLD      ,XREF      ,XTRAN     ,YI      ,
     ,YNOW      ,YOLD      ,YREF      ,YTRAN     ,ZI        ,
     ,ZNOW      ,ZOLD      ,ZREF      ,ZTRAN
      COMMON/IPARAM/          FMAX      ,IMAX      ,INOW      ,
     ,IORRAY    ,IOPRNT    ,IR        ,IRAY      ,JMAX      ,JNOW      ,JOLD    ,
     ,KINT      ,KMAX      ,KNOW      ,MMAX      ,NNOW      ,NSOR
      INTEGER F,FMAX
C********** FIND DISTANCE FROM POINT TO PLANE.
      DD=ALK(K)*XI+BEK(K)*YI+GAK(K)*ZI-DK(K)
      IF(DD)101,102,100
C********** POINT NOT ON ORIGIN SIDE.
  100 INPLAN=-1
      RETURN
C********** POINT ON ORIGIN SIDE.
  101 INPLAN=1
      RETURN
C********** POINT ON PLANE.
  102 CALL ERPRNT(6HINPLAN)
      RETURN
      END
      FUNCTION INSEG(J)
C*****************************************************************
C********** FUNCTION INSEG DETERMINES IF POINT(XI,YI,ZI) IS INSIDE
C********** SEGMENT NUMBER J.
C********** INSEG=1 FOR YES.
C********** INSEG=0 FOR NO.
C*****************************************************************
      COMMON /69/      ABCD(20,200)      ,ALRAY(500)      ,BERAY(500)
     1 ,COORDS(6,50)  ,E(40,200)         ,EBASE(200)      ,ESCR(20,200)
     2 ,GARAY(500)    ,RED(20,200)       ,TITLE(12)       ,VMAT(20)
     3 ,VOL(200)      ,XLAM(200)         ,XRAY(500)       ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/  ALK(200)          ,ALPHA(40)       ,BEK(200)
     1 ,BETA(40)      ,DEV(200)          ,DK(200)         ,EK(200)
     2 ,FLAM(200)     ,ELAMAT(20)        ,EMAT(20)        ,ENERGY(200)
     3 ,GAK(200)      ,GAMMA(40)         ,REF(20)         ,SCMAT(20)
     4 ,SUMRAY(200)   ,SUMSQR(200)       ,X(40)           ,XK(200)
     5 ,Y(40)         ,YK(200)           ,Z(40)           ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                  IFLAG(40)     ,IPOINT(50)     ,
     ,ISMAX(50)     ,ISOR(20)      ,JF(200)       ,JFL(200)       ,
     ,JL(200)       ,JM(200)       ,JN(200)       ,JP(200)        ,
     ,JRAY(200)     ,JSOR(50)      ,KBND(900)     ,KFLAG(200)     ,
     ,KP(200)       ,KTYP(200)     ,LAMP(50)      ,LANGLE(20)     ,
     ,LREFL(200)    ,LTYPE(20)     ,MAT(200)      ,MFL(20)        ,
     ,MMAT(20)      ,NUMRAY(200)
      COMMON/PARAMS/        AL         ,ALM       ,ALR       ,ALRF      ,BE      ,
     ,BEM       ,BER       ,BERF       ,DIS       ,DMIN      ,DZ        ,EPS     ,
     ,GA        ,GAM       ,GAR        ,GARF      ,PER       ,
     ,SUMRA     ,XI        ,XNOW       ,XOLD      ,XREF      ,XTRAN     ,YI      ,
     ,YNOW      ,YOLD      ,YREF       ,YTRAN     ,ZI        ,
     ,ZNOW      ,ZOLD      ,ZREF       ,ZTRAN
      COMMON/IPARAM/        FMAX       ,IMAX      ,INOW      ,
     ,ICPRAY    ,ICPENT    ,IR         ,IRAY      ,JMAX      ,JNOW      ,JOLD    ,
     ,KINT      ,KMAX      ,KNOW       ,MMAX      ,NNOW      ,NSOR
      INTEGER F,FMAX
C********** GET INDEX FOR BOUNDARY ARRAY FOR SEGMENT J.
      N=KP(J)
C********** GET INDEX K FOR ONE BOUNDARY OF SEGMENT J.
  104 K=IABS(KBND(N))
C********** GET GEOMETRY TYPE.
      KT=KTYP(K)
      KSIGN=KBND(N)
C********** BRANCH ON GEOMETRY TYPE.
      GO TO(100,200,300,400,500,600,700,800,900),KT
C********** IF POINT ON DESIRED SIDE OF PLANE, GO TO 101
  100 IF(INPLAN(K)*KSIGN)102,102,101
C********** IF POINT ON DESIRED SIDE OF CYLINDER, GO TO 101
  200 IF(INCYL(K)*KSIGN)102,102,101
C********** IF POINT ON DESIRED SIDE OF CONIC, GO TO 101
  300 IF(INCON(K)*KSIGN)102,102,101
C********** IF POINT ON DESIRED SIDE OF SPHERE, GO TO 101.
  400 IF(INSPH(K)*KSIGN)102,102,101
C********** IF POINT ON DESIRED SIDE OF CONE   , GO TO 101.
  500 IF(INCN(K)*KSIGN)102,102,101
C********** IF POINT ON DESIRED SIDE OF PARABOLOID, GO TO 101.
  600 IF(INPAR(K)*KSIGN)102,102,101
C********** IF POINT ON DESIRED SIDE OF HYPERBOLOID, GO TO 101.
  700 IF(INHYP(K)*KSIGN)102,102,101
C********** IF POINT ON DESIRED SIDE OF ELLIPSOID, GO TO 101.
  800 IF(INELL(K)*KSIGN)102,102,101

C********** IF POINT ON DESIRED SIDE OF HELIX, GO TO 101.
  900 IF(INHEL(K)*KSIGN)102,102,101
C********** LOOK AT NEXT BOUNDARY.
  101 N=N+1
      IF(KBND(N))104,103,104
C********** POINT IS INSIDE SEGMENT.
  103 INSEG=1
      GO TO 110
C********** POINT IS OUTSIDE SEGMENT.
  102 INSEG=0
  110 CONTINUE
      RETURN
      END
      FUNCTION INSPH(K)
C***********************************************************************
C********* FUNCTION INSPH FINDS IF POINT IS INSIDE SPHERE.
C***********************************************************************
      COMMON /69/      ABCO(20,200)       ,ALRAY(500)        ,BENAY(500)
     1 ,COORDS(6,50)  ,E(40,200)          ,EBASE(200)        ,ESCR(20,200)
     2 ,GARAY(500)    ,RED(20,200)        ,TITLE(12)         ,VMAT(20)
     3 ,VOL(200)      ,XLAM(200)          ,XRAY(500)         ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/  ALK(200)           ,ALPHA(40)         ,BEK(200)
     1 ,BETA(40)      ,DEV(200)           ,DK(200)           ,EK(200)
     2 ,ELAM(200)     ,ELAMAT(20)         ,EMAT(20)          ,ENERGY(200)
     3 ,GAK(200)      ,GAMMA(40)          ,REF(20)           ,SURMAT(20)
     4 ,SUMRAY(200)   ,SUMSQR(200)        ,X(40)             ,XK(200)
     5 ,Y(40)         ,YK(200)            ,Z(40)             ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                   IFLAG(40)      ,IPOINT(50)      ,
     ,ISMAX(50)     ,ISCR(20)         ,JF(200)        ,JFL(200)        ,
     ,JL(200)       ,JM(200)          ,JN(200)        ,JP(200)         ,
     ,JRAY(200)     ,JSCR(50)         ,KBND(900)      ,KFLAG(200)      ,
     ,KP(200)       ,KTYP(200)        ,LAMP(50)       ,LANGLE(20)      ,
     ,LREFL(200)    ,LTYPE(20)        ,MAT(200)       ,MFL(20)         ,
     ,NMAT(20)      ,NUMRAY(200)
      COMMON/PARAMS/          AL        ,ALN       ,ALR       ,ALRF      ,RE      ,
     ,BEN       ,BER       ,BERF      ,DIS       ,DMIN      ,DZ        ,EPS     ,
     ,GA        ,GAN       ,GAR       ,GARF      ,PER       ,
     ,SUMRA     ,XI        ,XNOW      ,XOLD      ,XREF      ,XTRAN     ,YI      ,
     ,YNOW      ,YOLD      ,YREF      ,YTRAN     ,ZI        ,
     ,ZNOW      ,ZOLD      ,ZREF      ,ZTRAN
      COMMON/IPARAM/          FMAX      ,IMAX      ,INOW      ,
     ,ICPRAY    ,ICPRNT    ,IR        ,I  AY     ,JMAX      ,JNOW      ,JOLD    ,
     ,KINT      ,KMAX      ,KNOW      ,MMAX      ,NNOW      ,NSOR
      INTEGER F,FMAX
C********* CALCULATE DISTANCE TO CENTER OF SPHERE.
      SS=(XI-XK(K))**2+(YI-YK(K))**2+(ZI-ZK(K))**2
C********* IF DISTANCE GREATER THAN RADIUS, POINT IS OUTSIDE.
      IF(SS-DK(K)**2)101,101,102
C********* POINT IS INSIDE.
  101 INSPH=1
      RETURN
C********* POINT IS OUTSIDE.
  102 INSPH=-1
      RETURN
      END
      SUBROUTINE INTCN(K,DHIT)
C*************************************************************************
C********** INTCN FINDS INTERSECTION OF RAY WITH A CONE. SEE WRITEUP
C********** FOR EQUATIONS USED.
C*************************************************************************
      COMMON /69/      ABCO(20,200)      ,ALRAY(500)      ,BERAY(500)
     1 ,COORDS(6,50)  ,E(40,200)         ,EBASE(200)      ,ESOR(20,200)
     2 ,GARAY(500)    ,RED(20,200)       ,TITLE(12)       ,VMAT(20)
     3 ,VOL(200)      ,XLAM(200)         ,XRAY(500)       ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/  ALK(200)          ,ALPHA(40)       ,BEK(200)
     1 ,BETA(40)      ,DEV(200)          ,DK(200)         ,EK(200)
     2 ,ELAM(200)     ,ELAMAT(20)        ,EMAT(20)        ,ENERGY(200)
     3 ,GAK(200)      ,GAMMA(40)         ,REF(20)         ,SCRMAT(20)
     4 ,SUMRAY(200)   ,SUMSOR(200)       ,X(40)           ,XK(200)
     5 ,Y(40)         ,YK(200)           ,Z(40)           ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                IFLAG(40)        ,IPOINT(50)       ,
     *ISMAX(50)       ,ISOR(20)       ,JF(200)         ,JFL(200)         ,
     *JL(200)         ,JM(200)        ,JN(200)         ,JP(200)          ,
     *JRAY(200)       ,JSOR(50)       ,KBND(900)       ,KFLAG(200)       ,
     *KP(200)         ,KTYP(200)      ,LAMP(50)        ,LANGLE(20)       ,
     *LREFL(200)      ,LTYPE(20)      ,MAT(200)        ,MFL(20)          ,
     *NMAT(20)        ,NUMRAY(200)
      COMMON/PARAMS/       AL        ,ALN       ,ALR       ,ALRF      ,RE      ,
     *BEN      ,BER      ,BERF      ,DIS       ,DMIN      ,DZ        ,EPS     ,
     *GA       ,GAN      ,GAR       ,GANF      ,PER       ,
     *SUMRA    ,XI       ,XNOW      ,XCLO      ,XREF      ,XTRAN     ,YI      ,
     *YNOW     ,YOLD     ,YREF      ,YTRAN     ,ZI        ,
     *ZNOW     ,ZOLD     ,ZREF      ,ZTRAN     
      COMMON/IPARAM/       FMAX      ,IMAX      ,INOW      ,
     *IOPRAY   ,IOPRNT   ,IR        ,IRAY      ,JMAX      ,JNOW      ,JOLD    ,
     *KINT     ,KMAX     ,KNOW      ,MMAX      ,NNOW      ,NSOR
      INTEGER F,FMAX
C********** CALCULATE PARAMETERS NEEDED FOR DISTANCE EQUATION.
      DELX=XI-XK(K)
      DELY=YI-YK(K)
      DELZ=ZI-ZK(K)
      C=DELZ**2-DK(K)*(DELX**2+DELY**2+DELZ**2)
      B=(1.0-DK(K))*GA*DELZ-DK(K)*(AL*DELX+BE*DELY)
      A=GA**2-DK(K)
      SQ=B**2-A*C
      IF(SQ)101,102,102
  102 ROOT=SQRT(SQ)
C********** CALCULATE BOTH ROOTS AND CHOOSE THE SMALLEST POSITIVE
C********** ROOT THAT IS IN THE DESIRED HALF OF CONE
      DHIT1=(-B+ROOT)/A
      DHIT2=(-B-ROOT)/A
      IF(DHIT1)101,103,103
  103 EPL=(ZI+DHIT1*GA-ZK(K))*EK(K)
      EMI=(ZI+DHIT2*GA-ZK(K))*EK(K)
      IF(DHIT2)105,105,104
  104 IF(EMI)105,105,106
  105 IF(EPL)101,101,107
  106 DHIT=DHIT2
      GO TO 108
  107 DHIT=DHIT1
      GO TO 108
  101 DHIT=1.E+21
  108 CALL DEBUG(6HINTCN )
      RETURN

      END
      SUBROUTINE INTCON(K,DHIT)
C*****************************************************************
C********* SUBROUTINE INTCON CALCULATES THE DISTANCE FROM POINT
C********* XI,YI,ZI TO THE POINT WHERE THE RAY INTERSECTS CONIC
C********* BOUNDARY K. SEE WRITEUP FOR EXACT EQUATIONS USED.
C*****************************************************************
      COMMON /69/         ABCO(20,200)     ,ALRAY(500)      ,BERAY(500)
     1 ,COORDS(6,50)   ,E(40,200)       ,EPHASE(200)     ,ESOM(20,200)
     2 ,GARAY(500)     ,RED(20,200)     ,TITLE(12)       ,VMAT(20)
     3 ,VOL(200)       ,XLAM(200)       ,XRAY(500)       ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/  ALK(200)         ,ALPHA(40)       ,BEK(200)
     1 ,BETA(40)       ,DEV(200)        ,DK(200)         ,EK(200)
     2 ,FLAM(200)      ,ELAMAT(20)      ,EMAT(20)        ,ENERGY(200)
     3 ,GAK(200)       ,GAMMA(40)       ,REF(20)         ,SORMAT(20)
     4 ,SUMRAY(200)    ,SUMSOR(200)     ,X(40)           ,XK(200)
     5 ,Y(40)          ,YK(200)         ,Z(40)           ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                  IFLAG(40)       ,IPOINT(50)     ,
     *ISMAX(50)      ,ISOR(20)       ,JF(200)        ,JFL(200)       ,
     *JL(200)        ,JM(200)        ,JN(200)        ,JP(200)        ,
     *JRAY(200)      ,JSOR(50)       ,KBND(900)      ,KFLAG(200)     ,
     *KP(200)        ,KTYP(200)      ,LAMP(50)       ,LANGLE(20)     ,
     *LREFL(200)     ,LTYPE(20)      ,MAT(200)       ,MFL(20)        ,
     *NMAT(20)       ,NUMRAY(200)
      COMMON/PARAMS/      AL         ,ALM        ,ALR        ,ALRF       ,BE         ,
     *BEM        ,BER        ,BERF       ,DIS        ,DMIN       ,DZ         ,EPS        ,
     *GA         ,GAM        ,GAR        ,GARF       ,PER        ,
     *SUMRA      ,XI         ,XNOW       ,XOLD       ,XREF       ,XTRAN      ,YI         ,
     *YNOW       ,YOLD       ,YREF       ,YTRAN      ,ZI         ,
     *ZNOW       ,ZOLD       ,ZREF       ,ZTRAN
      COMMON/IPARAM/      FMAX       ,IMAX       ,INOW       ,
     *IOPRAY     ,ICPRNT     ,IR         ,IRAY       ,JMAX       ,JNOW       ,JOLD       ,
     *KINT       ,KMAX       ,KNOW       ,MMAX       ,MNOW       ,NSOR
      INTEGER F,FMAX
C********* CALCULATE COEFFICIENTS FOR DISTANCE EQUATION.
      DX=XI-XK(K)
      DY=YI-YK(K)
      IF(ABS((GA)**2-1.0)-1.E-6)104,104,101
  101 COSTH=SQRT(1.0-GA**2)
      ALL=AL/COSTH
      BEL=BE/COSTH
      CALL CHECK(6HINTCON,ALL,BEL,0,0)
      EE=DX*ALL+DY*BEL
      FF=DX*ALK(K)+DY*BEK(K)
      GG=ALK(K)*ALL+BEK(K)*BEL
      BS=DX**2+DY**2
      PP=1.0-(EK(K)**2)*(GG**2)
      IF(ABS(PP)-1.E-20)104,104,102
  102 HH=EE-EK(K)**2*GG*(FF+DK(K))
      QQ=BS-EK(K)**2*(FF+DK(K))**2
      HSPQ=HH**2-PP*QQ
      IF(HSPQ)104,103,103
C********* FIND BOTH ROOTS OF THE EQUATION AND CHOOSE THE SHORTEST
C********* POSITIVE ROOT.
  103 ROOT=SQRT(HSPQ)
      DHIT1=(-HH-ROOT)/(PP*COSTH)
      DHIT2=(-HH+ROOT)/(PP*COSTH)
      DHIT=AMIN1(DHIT1,DHIT2)
      IF(DHIT)105,105,107
  105 DHIT=AMAX1(DHIT1,DHIT2)

      IF(DHIT)104,104,107
  104 DHIT=1.E21
  107 CONTINUE
      CALL DEBUG(6HINTCON)
      RETURN
      END
      SUBROUTINE INTCYL(K,DHIT)
C*****************************************************************
C********* SUBROUTINE INTCYL CALCULATES THE DISTANCE FROM POINT
C********* XI,YI,ZI IN THE DIRECTION AL,BE,GA TO THE POINT WHERE THE
C********* RAY INTERSECTS CYLINDRICAL BOUNDARY K. SEE WRITEUP FOR
C********* EXACT EQUATIONS USED.
C*****************************************************************
      COMMON /69/      ABCO(20,200)     ,ALRAY(500)       ,BERAY(500)
     1 ,COORDS(6,50)   ,E(40,200)       ,EBASE(200)       ,ESOR(20,200)
     2 ,GARAY(500)     ,RED(20,200)     ,TITLE(12)        ,VMAT(20)
     3 ,VOL(200)       ,XLAM(200)       ,XRAY(500)        ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/  ALK(200)         ,ALPHA(40)        ,BEK(200)
     1 ,BETA(40)       ,DEV(200)        ,DK(200)          ,EK(200)
     2 ,ELAM(200)      ,ELAMAT(20)      ,EMAT(20)         ,ENERGY(200)
     3 ,GAK(200)       ,GAMMA(40)       ,REF(20)          ,SGMAT(20)
     4 ,SUMRAY(200)    ,SUMSOR(200)     ,X(40)            ,XK(200)
     5 ,Y(40)          ,YK(200)         ,Z(40)            ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                     IFLAG(40)     ,IPOINT(50)    ,
     ,ISMAX(50)     ,ISOR(20)          ,JF(200)       ,JFL(200)      ,
     ,JL(200)       ,JM(200)           ,JN(200)       ,JP(200)       ,
     ,JRAY(200)     ,JSOR(50)          ,KBND(900)     ,KFLAG(200)    ,
     ,KP(200)       ,KTYP(200)         ,LAMP(50)      ,LANGLE(20)    ,
     ,LREFL(200)    ,LTYPE(20)         ,MAT(200)      ,MFL(20)       ,
     ,NMAT(20)      ,NUMRAY(200)
      COMMON/PARAMS/         AL        ,ALN       ,ALR       ,ALRF      ,BE       ,
     ,BEN       ,BER       ,BERF      ,DIS       ,DMIN      ,DZ        ,EPS      ,
     ,GA        ,GAN       ,GAR       ,GARF      ,PER       ,
     ,SUMRA     ,XI        ,XNOW      ,XOLD      ,XREF      ,XTRAN     ,YI       ,
     ,YNOW      ,YOLD      ,YREF      ,YTRAN     ,ZI        ,
     ,ZNOW      ,ZOLD      ,ZREF      ,ZTRAN
      COMMON/IPARAM/         FMAX      ,IMAX      ,INOW      ,
     ,IOPRAY    ,IOPRNT    ,IR        ,IRAY      ,JMAX      ,JNOW      ,JOLD     ,
     ,KINY      ,KMAX      ,KNOW      ,MMAX      ,MNOW      ,NSOR
      INTEGER F,FMAX
C********* CALCULATE COEFFICIENTS FOR DISTANCE EQUATION.
      XX=AL*ALK(K)+BE*BEK(K)+GA*GAK(K)
      OMXS=1.0-XX**2
      IF(ABS(OMXS)-1.E-6)101,101,102
  102 DELX=XI-XK(K)
      DELY=YI-YK(K)
      DELZ=ZI-ZK(K)
      YY=AL*DELX+BE*DELY+GA*DELZ
      ZZ=ALK(K)*DELX+BEK(K)*DELY+GAK(K)*DELZ
      ASQ=DELX**2+DELY**2+DELZ**2
      SQTERM=(YY-ZZ*XX)**2-(OMXS)*(ASQ-ZZ**2-DK(K)**2)
      IF(SQTERM)101,103,103
C********* FIND BOTH ROOTS OF THE EQUATION AND CHOOSE THE SHORTEST
C********* POSITIVE ROOT.
  103 ROOT=SQRT(SQTERM)
      ZXMY=ZZ*XX-YY
      DHIT1=(ZXMY+ROOT)/OMXS
      DHIT2=(ZXMY-ROOT)/OMXS
      DHIT=AMIN1(DHIT1,DHIT2)
      IF(DHIT)104,104,105
  104 DHIT=AMAX1(DHIT1,DHIT2)
      IF(DHIT)101,101,105
  101 DHIT=1.E+21
  105 CONTINUE
      CALL DEBUG(6HINTCYL)

      RETURN
      END
      SUBROUTINE INTDAT(IT,LT)
C*******************************************************************
C********** SUBROUTINE INTDAT CALLS THE DESIRED ROUTINE TO
C********** CALCULATE WAVELENGTH DEPENDENT RAY INTENSITIES.
C*******************************************************************
      COMMON /69/        ABCO(20,200)      ,ALRAY(500)      ,BEHAY(500)
     1 ,COORDS(6,50)  ,E(40,200)        ,EBASE(200)      ,ESOR(20,200)
     2 ,GARAY(500)    ,RED(20,200)      ,TITLE(12)       ,VMAT(20)
     3 ,VOL(200)      ,XLAM(200)        ,XRAY(500)       ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/  ALK(200)          ,ALPHA(40)       ,BEK(200)
     1 ,BETA(40)      ,DEV(200)         ,DK(200)         ,EK(200)
     2 ,ELAM(200)     ,ELAMAT(20)       ,EMAT(20)        ,ENERGY(200)
     3 ,GAK(200)      ,GAMMA(40)        ,REF(20)         ,SORMAT(20)
     4 ,SUMRAY(200)   ,SUMSOR(200)      ,X(40)           ,XK(200)
     5 ,Y(40)         ,YK(200)          ,Z(40)           ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                  IFLAG(40)      ,IPOINT(50)      ,
     ,ISMAK(50)      ,ISOR(20)        ,JF(200)       ,JFL(200)        ,
     ,JL(200)        ,JM(200)         ,JN(200)       ,JP(200)         ,
     ,JRAY(200)      ,JSOR(50)        ,KBND(900)     ,KFLAG(200)      ,
     ,KP(200)        ,KTYP(200)       ,LAMP(50)      ,LANGLE(20)      ,
     ,LREFL(200)     ,LTYPE(20)       ,MAT(200)      ,MFL(20)         ,
     ,NMAY(20)       ,NUMRAY(200)
      COMMON/PARAMS/      AL        ,ALN       ,ALR       ,ALRF      ,RE        ,
     ,BEN       ,FER       ,BERF      ,DIS       ,DMIN      ,DZ        ,EPS       ,
     ,GA        ,GEN       ,GAR       ,GARF      ,PER       ,
     ,SUMRA     ,XI        ,XNOW      ,XOLD      ,XREF      ,XTRAN     ,YI        ,
     ,YNOW      ,YOLD      ,YREF      ,YTRAN     ,ZI        ,
     ,ZNOW      ,ZOLD      ,ZREF      ,ZTRAN     
      COMMON/IPARAM/      FMAX      ,IMAX      ,INOW      ,
     ,ICPRAY    ,ICPRNT    ,IF        ,IRAY      ,JMAX      ,JNOW      ,JOLD      ,
     ,KINT      ,KMAX      ,KNOW      ,NMAX      ,NNOW      ,NSOR
      INTEGER F,FMAX
      DIMENSION TSTG(200)
C********** GO TO DESIRED CALL.
      GO TO(100,200,300,400,500,600,700,800,900),IT
  100 CALL INTEN1(XLAM,FMAX,TSTG,LT)
      GO TO 110
  200 CALL INTEN2(XLAM,FMAX,TSTG,LT)
      GO TO 110
  300 CALL INTEN3(XLAM,FMAX,TSTG,LT)
      GO TO 110
  400 CALL INTEN4(XLAM,FMAX,TSTG,LT)
      GO TO 110
  500 CALL INTEN5(XLAM,FMAX,TSTG,LT)
      GO TO 110
  600 CALL INTEN6(XLAM,FMAX,TSTG,LT)
      GO TO 110
  700 CALL INTEN7(XLAM,FMAX,TSTG,LT)
      GO TO 110
  800 CALL INTEN8(XLAM,FMAX,TSTG,LT)
      GO TO 110
  900 CALL INTEN9(XLAM,FMAX,TSTG,LT)
  110 DO 101 F=1,FMAX
      ESOR(LT,F)=TSTG(F)
  101 CONTINUE
      RETURN
      END
      SUBROUTINE INTELL(K,DHIT)
C*****************************************************************
C********** INTELL FINDS THE INTERSECTION DISTANCE OF A RAY WITH
C********** AN ELLIPSOID.  SEE WRITUP FOR EQUATIONS USED.
C*****************************************************************
      COMMON /69/        ABCO(20,200)       ,ALRAY(500)        ,BERAY(500)
     1 ,COORDS(6,50)   ,E(40,200)         ,EBASE(200)        ,ESOR(20,200)
     2 ,GARAY(500)     ,RED(20,200)       ,TITLE(12)         ,VMAT(20)
     3 ,VOL(200)       ,XLAM(200)         ,XRAY(500)         ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/  ALK(200)           ,ALPHA(40)         ,BEK(200)
     1 ,BETA(40)       ,DEV(200)          ,DK(200)           ,EK(200)
     2 ,ELAM(200)      ,ELAMAT(20)        ,EMAT(20)          ,ENERGY(200)
     3 ,GAK(200)       ,GAMMA(40)         ,REF(20)           ,SUMMAT(20)
     4 ,SUMRAY(200)    ,SUMSOR(200)       ,X(40)             ,XK(200)
     5 ,Y(40)          ,YK(200)           ,Z(40)             ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                    IFLAG(40)      ,IPOINT(50)     ,
     ,ISMAX(50)      ,ISOR(20)        ,JF(200)       ,JFL(200)       ,
     ,JL(200)        ,JM(200)         ,JN(200)       ,JP(200)        ,
     ,JRAY(200)      ,JSOR(50)        ,KBND(900)     ,KFLAG(200)     ,
     ,KP(200)        ,KTYP(200)       ,LAMP(50)      ,LANGLE(20)     ,
     ,LREFL(200)     ,LTYPE(20)       ,MAT(200)      ,MFL(20)        ,
     ,NMAT(20)       ,NUMRAY(200)
      COMMON/PARAMS/        AL         ,ALN        ,ALR        ,ALRF       ,BE       ,
     ,BEN       ,BEN       ,BERF       ,DIS        ,DMIN       ,DZ         ,EPS      ,
     ,GA        ,GAN       ,GAR        ,GANF       ,PEN        ,
     ,SUMRA     ,XI        ,XNOW       ,XOLD       ,XREF       ,XTRAN      ,YI       ,
     ,YNOW      ,YOLD      ,YREF       ,YTRAN      ,ZI         ,
     ,ZNOW      ,ZOLD      ,ZREF       ,ZTRAN      -
      COMMON/IPARAM/        FMAX       ,IMAX       ,INOW       ,
     ,IOPRAY    ,IOPRNT    ,IR         ,IRAT       ,JMAX       ,JNOW       ,JOLD     ,
     ,KINT      ,KMAX      ,KNOW       ,MMAX       ,NNOW       ,NSOR
      INTEGER F,FMAX
C********** CALCULATE COEFFICIENTS NEEDED IN EQUATIONS.
      DELX=XI-XK(K)
      DELY=YI-YK(K)
      DELZB=ZI-ZK(K)-EK(K)
      BSC=EK(K)**2
      C=1.0-(DELX**2+DELY**2)/DK(K)-DELZB**2/BSQ
      B=-((AL*DELX+BE*DELY)/DK(K)+GA*DELZB/BSQ)
      A=-((AL**2+BE**2)/DK(K)+GA**2/BSQ)
      SQ=B**2-A*C
      IF(SQ)101,102,102
  102 ROOT=SQRT(SQ)
C********** FIND BOTH ROOTS AND CHOOSE SMALLEST POSITIVE ROOT.
      DHIT1=(-B+ROOT)/A
      DHIT2=(-B-ROOT)/A
      DHIT=AMIN1(DHIT1,DHIT2)
      IF(DHIT)104,104,105
  104 DHIT=AMAX1(DHIT1,DHIT2)
      IF(DHIT)101,101,105
  101 DHIT=1.E+21
  105 CONTINUE
      CALL DEBUG(6HINTELL)
      RETURN
      END
      SUBROUTINE INTHEL(K,CHI)
C*****************************************************************
C********** INTHEL LOOKS FOR THE NEAREST INTERSECTION OF A RAY WITH
C********** HELICAL SURFACE. INTHEL PRIMARILY DETERMINES WHICH(IF ANY)
C********** COILS ARE POSSIBLE FOR INTERSECTIONS AND CALLS DCALC FOR
C********** EACH POSSIBLE COIL.
C*****************************************************************
      COMMON /69/     ABCD(20,200)      ,ALRAY(500)       ,BERAY(500)
     1 ,COORDS(6,50)  ,E(40,200)        ,EBASE(200)       ,ESOR(20,200)
     2 ,GARAY(500)    ,RED(20,200)      ,TITLE(12)        ,VMAT(20)
     3 ,VOL(200)      ,XLAM(200)        ,XRAY(500)        ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/  ALK(200)         ,ALPHA(40)        ,BEK(200)
     1 ,BETA(40)      ,DEV(200)         ,DK(200)          ,EK(200)
     2 ,ELAM(200)     ,ELAMAT(20)       ,EMAT(20)         ,ENERGY(200)
     3 ,GAK(200)      ,GAMMA(40)        ,REF(20)          ,SGMAT(20)
     4 ,SUMRAY(200)   ,SUMSOR(200)      ,X(40)            ,XK(200)
     5 ,Y(40)         ,YK(200)          ,Z(40)            ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                  IFLAG(40)       ,IPOINT(50)      ,
     ,ISPAA(50)     ,ISOR(20)         ,JF(200)        ,JFL(200)        ,
     ,JL(200)       ,JM(200)          ,JK(200)        ,JP(200)         ,
     ,JRAY(200)     ,JSOR(50)         ,KBND(900)      ,KFLAG(200)      ,
     ,KP(200)       ,KTYP(200)        ,LAMP(50)       ,LANGLE(20)      ,
     ,LREFL(200)    ,LTYPE(20)        ,MAT(200)       ,MFL(20)         ,
     ,NMAT(20,      ,NUMRAY(200)
      COMMON/PARAMS/       AL         ,ALN        ,ALR        ,ALRF       ,BE        ,
     ,BEN        ,BER        ,BERF       ,DIS        ,DMIN       ,DZ        ,EPS       ,
     ,GA         ,GAN        ,GAR        ,GARF       ,PER        ,
     ,SUMRA      ,XI         ,XNOW       ,XOLD       ,XREF       ,XTRAN     ,YI        ,
     ,YNOW       ,YOLD       ,YREF       ,YTRAN      ,ZI         ,
     ,ZNOW       ,ZOLD       ,ZREF       ,ZTRAN
      COMMON/IPARAM/       FMAX       ,IMAX       ,INOW       ,
     ,IOPRAY     ,ICPRNT     ,IR         ,IRAY       ,JMAX       ,JNOW      ,JOLD      ,
     ,KINT       ,KMAX       ,KNOW       ,NMAX       ,NNOW       ,NSOR
      INTEGER F,FMAX
      COMMON/HELCOM/A,ABAR,B,BI,BIP,BP,CAP,DELTH,DELX,DELY,DELZ,DHIT,
     ,PSIZ,REV,R,D,STH,TH,TH1,SQRKS,RKS,CSTH,SNTH,RCSTH,RSNTH,BSTH,
     ,ACOSTAN,THZ,DTHZ
      DHIT=1.E+21
C********** CALCULATE PARAMETERS NEEDED.
      CAP=ALK(K)
      RHO=BEK(K)
      A=RK(K)
      ABAR=A**2/2.0
      CALL PERTRB(AL,BE,GA)
      SI=0.0
      DELX=XK(K)-XI
      DELY=YK(K)-YI
      DELZ=ZK(K)-ZI
      TMP=AL*DELY-BE*DELX
      TMP1=DELX**2+DELY**2+DELZ**2
      FRU=SIGN(1.0,TMP)*SQRT(AL**2+BE**2)
      SB=(DELX*AL+DELY*BE)/(AL**2+BE**2)
      BSQ=(DELX-SB*AL)**2+(DELY-SB*BE)**2
      ROUTSQ=(R-D+A)**2
      RINSQ=(R-D-A)**2
C********** IF POINT ON RAY NEAREST TO HELICAL AXIS NOT INSIDE OUTER
C********** RADIUS OF HELIX, RETURN.
      IF(BSQ-ROUTSQ)101,110,110
  101 RHOSQ=DELX**2+DELY**2
```

```
      UOUT=SQRT(ROUTSQ-BSQ)/ABS(FMU)
C********* IF STARTING POINT NOT INSIDE OUTER RADIUS, GO TO 102.
      IF(RHOSQ-ROUTSQ)104,104,102
  102 DOT=(AL*DELX+BE*DELY)
C********* IF RAY MOVING AWAY FROM HELIX, RETURN.
      IF(DOT)110,110,103
C********* CALCULATE COIL NUMBERS AND OTHER NEEDED PARAMETERS.
  103 S1=SB-UOUT
  104 S4=SB+UOUT
      REV=6.28318531*SIGN(1.0,GA*CAP)
      XB=XI+AL*SB
      YB=YI+BE*SB
      ZB=ZI+GA*SB
      IF(ABS(YK(K)-YB)-1.E-5)140,140,141
  140 IF(ABS(XK(K)-XB)-1.E-5)142,142,141
  142 PSIZ=ATAN2(-DELX,DELY)
      GO TO 143
  141 PSIZ=ATAN2(YK(K)-YB,XK(K)-XB)
  143 N1=NINT(S1)
      IF(N1.GT.100) GO TO 110
      N4=NINT(S4)
      SQT=RINSQ-BSQ
C********* IF POINT ON RAY NEAREST TO AXIX IS INSIDE INNER RADIUS, GO TO
      IF(SQT)106,106,105
  106 N2=10**5
      N3=10**8
      GO TO 107
  105 UIN=SQRT(SQT)/ABS(FMU)
      S2=SB-UIN
      S3=SB+UIN
      N2=NINT(S2)
      N3=NINT(S3)
      IF(S[illegible].LT. 0 .AND. [illegible] .GT. 100) GO TO 110
  107 BCL=SQRT(BSQ)
C********* TEST TO SEE IF N5 AND N6 ARE NEEDED.
      IF(FMU*CAP/GA-BCL)113,113,108
  108 XLA=SQRT(CAP*BCL/GA/FMU-BSQ/FMU**2)
      S5=SB+XLA
      S6=SB-XLA
      N5=NINT(S5)
      N6=NINT(S6)
      IF(N5-N6)109,113,113
  109 IF(XLA**2+BSQ-ROUTSQ)114,114,111
111             CONTINUE
      CALL DCALC(N1)
      IF(N1-N5)112,110,112
  112 CALL DCALC(N5)
      GO TO 110
  113 N5=10**8
      N6=10**8
C********* LOOP THROUGH POSSIBLE COILS UNTIL AN INTERSECTION IS FOUND
C********* OR UNTIL ALL POSSIBLE COILS HAVE BEEN TRIED.
  114 N=N1
  123 IF(N-N2)117,117,115
  115 IF(N-N3)116,117,117
  116 N=N3
  117 IF(N-N6)119,118,119
  118 N=N5
119             CONTINUE
      IF(N.GT.200)GO TO 110
C********* LOOK FOR INTERSECTION WITH COIL N.
      CALL DCALC(N)

      IF(N-N5)121,120,121
120   N=N6
      GO TO 119
121   IF(DMIT-1.E+20)110,122,122
122   N=N+1
      IF(N-N4)123,123,110
110   CALL DEBUG(6HINTHEL)
      DMI=DMIT
      RETURN
      END
      SUBROUTINE INTHYP(K,DHIT)
C*****************************************************************
C********* INTHYP FINDS THE INTERSECTION DISTANCE OF A RAY WITH
C********* A HYPERBOLOID. SEE WRITEUP FOR EQUATIONS USED.
C*****************************************************************
       COMMON /69/      ABCO(20,200)      ,ALRAY(500)       ,BERAY(500)
     1 ,COORDS(6,50)   ,E(46,200)         ,ERASE(200)       ,ESOR(20,200)
     2 ,GARAY(500)     ,RED(20,200)       ,TITLE(12)        ,VMAT(20)
     3 ,VOL(200)       ,XLAM(200)         ,XRAY(500)        ,YMAT(500)
     4 ,ZRAY(500)
       COMMON /ARRAYS/  ALK(200)          ,ALPHA(40)        ,BEK(200)
     1 ,BETA(40)       ,DEV(200)          ,DK(200)          ,EK(200)
     2 ,FLAM(200)      ,ELAMAT(20)        ,EMAT(20)         ,ENERGY(200)
     3 ,GAK(200)       ,GAMMA(40)         ,REF(20)          ,SQMAT(20)
     4 ,SUMRAY(200)    ,SUMSOR(200)       ,X(40)            ,XK(200)
     5 ,Y(40)          ,YK(200)           ,Z(40)            ,ZK(200)
     6 ,ZLAM(20)
       COMMON/IARRAY/                  IFLAG(40)         ,IPOINT(50)      ,
     ,ISMAX(50)      ,ISOR(20)         ,JF(200)          ,JFL(200)        ,
     ,JL(200)        ,JM(200)          ,JN(200)          ,JP(200)         ,
     ,JRAY(200)      ,JSOR(50)         ,KBND(900)        ,KFLAG(200)      ,
     ,KP(200)        ,KTYP(200)        ,LAMP(50)         ,LANGLE(20)      ,
     ,LPFFL(200)     ,LTYPE(20)        ,MAT(200)         ,MFL(20)         ,
     ,MMAT(20)       ,NUMRAY(200)
       COMMON/PARAMS/            AL        ,ALN        ,ALR        ,ALRF
     ,BEN      ,BER       ,BERF      ,DIS        ,DMIN       ,DZ         ,RE    ,
     ,GA       ,GAN       ,GAR       ,GARF       ,PER        ,           ,EPS   ,
     ,SUMRA    ,XI        ,XNOW      ,XOLD       ,XREF       ,XTRAN      ,YI    ,
     ,YNOW     ,YOLD      ,YREF      ,YTRAN      ,ZI         ,
     ,ZNOW     ,ZOLD      ,ZREF      ,ZTRAN
       COMMON/IPARAM/            FMAX      ,IMAX       ,INOW       ,
     ,IOPRAY   ,IOPRNT    ,IR        ,IRAY       ,JMAX       ,JNOW       ,JOLD  ,
     ,KINT     ,KMAX      ,KNOW      ,MMAX       ,NNOW       ,NSOR
       INTEGER F,FMAX
C********* CALCULATE COEFFICIENTS NEEDED FOR EQUATIONS.
      DELX=XI-XK(K)
      DELY=YI-YK(K)
      DELZH=ZI-ZK(K)+EK(K)
      A=(GA/EK(K))**2-(AL**2+BE**2)/DK(K)
      B=GA*DELZP/(EK(K)**2)-(AL*DELX+BE*DELY)/DK(K)
      C=-1.0-(DELX**2+DELY**2)/DK(K)+(DELZH**2)/(EK(K)**2)
      SQ=B**2-A*C
      IF(SQ)101,102,102
  102 ROOT=SQRT(SQ)
C********* CALCULATE BOTH ROOTS AND CHOOSE THE SMALLEST POSITIVE
C********* VALUE THAT LIES IN THE DESIRED SHEET.
      DHIT1=(-B+ROOT)/A
      DHIT2=(-B-ROOT)/A
      EPL=(ZI+DHIT1*GA-ZK(K))*GAK(K)
      EMI=(ZI+DHIT2*GA-ZK(K))*GAK(K)
      IF(EPL)104,104,103
  104 IF(EMI)101,101,105
  105 DHIT=DHIT2
      GO TO 106
  103 IF(EMI)107,107,108
  107 DHIT=DHIT1
      GO TO 106
  108 DHIT=AMIN1(DHIT1,DHIT2)
      IF(DHIT)109,109,110
  109 DHIT=AMAX1(DHIT1,DHIT2)
  106 IF(DHIT)101,101,110

  101 DHIT=1.E+21
  110 CALL DEBUG(6HINTHYP)
      RETURN
      END
      SUBROUTINE INTPAR(K,DHIT)
C*************************************************************************
C********** INTPAR FINDS THE DISTANCE TO THE NEAREST INTERSECTION OF*******
C********** A RAY WITH A PARABOLA. SEE WRITEUP FOR EQUATIONS USED.
C*************************************************************************
      COMMON /69/       ABCD(20,200)     ,ALRAY(500)       ,BERAY(500)
     1 ,COORDS(6,50)   ,E(40,200)       ,EBASE(200)       ,ESOR(20,200)
     2 ,GARAY(500)     ,RED(20,200)     ,TITLE(12)        ,VMAT(20)
     3 ,VOL(200)       ,XLAM(200)       ,XRAY(500)        ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/   ALK(200)         ,ALPHA(40)        ,BEK(200)
     1 ,BETA(40)       ,DEV(200)        ,DK(200)          ,EK(200)
     2 ,FLAM(200)      ,ELAMAT(20)      ,EMAT(20)         ,ENERGY(200)
     3 ,GAK(200)       ,GAMMA(40)       ,REF(20)          ,SCHMAT(20)
     4 ,SUMRAY(200)    ,SUMSQH(200)     ,X(40)            ,XK(200)
     5 ,Y(40)          ,YK(200)         ,Z(40)            ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                    IFLAG(40)
     *,ISMAX(50)       ,ISOR(20)        ,JF(200)          ,IPOINT(50)      ,
     *,JL(200)         ,JM(200)         ,JN(200)          ,JFL(200)        ,
     *,JRAY(200)       ,JSOR(50)        ,KBND(900)        ,JP(200)         ,
     *,KP(200)         ,KTYP(200)       ,LAMP(50)         ,KFLAG(200)      ,
     *,LREFL(200)      ,LTYPE(20)       ,MAT(200)         ,LANGLE(20)      ,
     *,MMAT(20)        ,NUMRAY(200)                       ,MFL(20)         ,
      COMMON/PARAMS/            AL         ,ALN        ,ALR        ,ALRF       ,HE    ,
     *,BEN       ,BER       ,BERF       ,DIS        ,DMIN       ,DZ         ,EPS   ,
     *,GA        ,GAN       ,GAR        ,GARF       ,PER        ,           ,      ,
     *,SUMRA     ,XI        ,XNOW       ,XOLD       ,XREF       ,XTRAN      ,YI    ,
     *,YNOW      ,YOLD      ,YREF       ,YTRAN      ,ZI         ,
     *,ZNOW      ,ZOLD      ,ZREF       ,ZTRAN
      COMMON/IPARAM/            FMAX       ,IMAX       ,INOW       ,
     *,IOPRAY    ,IOPRNT    ,IR         ,IRAY       ,JMAX       ,JNOW       ,JOLD  ,
     *,KINT      ,KMAX      ,KNOW       ,NMAX       ,NNOW       ,NSOR
      INTEGER F,FMAX
C********** CALCULATE COEFFICIENTS NEEDED FOR EQUATIONS.
      DELX=XI-XK(K)
      DELY=YI-YK(K)
      DELZ=ZI-ZK(K)
      C=4.0*DK(K)*DELZ-DELX**2-DELY**2
      B=2.0*DK(K)*GA-AL*DELX-BE*DELY
      A=-(AL**2+BE**2)
      SQ=B**2-A*C
      IF(SQ)101,102,102
  102 ROOT=SQRT(SQ)
C********** FIND BOTH ROOTS AND CHOOSE SMALLEST POSITIVE VALUE.
      DHIT1=(-B+ROOT)/A
      DHIT2=(-B-ROOT)/A
      DHIT=AMIN1(DHIT1,DHIT2)
      IF(DHIT)104,104,105
  104 DHIT=AMAX1(DHIT1,DHIT2)
      IF(DHIT)101,101,105
  101 DHIT=1.E+21
  105 CONTINUE
      CALL DEBUG(6HINTPAR)
      RETURN
      END
      SUBROUTINE INTPLA(K,DHIT)
C*****************************************************************
C********** SUBROUTINE INTPLA CALCULATE THE DISTANCE FROM THE POINT
C********** XI,YI,ZI IN THE DIRECTION AL,BE,GA TO THE POINT WHERE THE
C********** RAY INTERSECTS THE PLANE BOUNDARY K.
C*****************************************************************
      COMMON /69/        ABCO(20,200)      ,ALRAY(500)       ,BERAY(500)
     1 ,COORDS(6,50)   ,E(40,200)        ,EBASE(200)       ,ESOR(20,200)
     2 ,GARAY(500)     ,RED(20,200)      ,TITLE(12)        ,VMAT(20)
     3 ,VOL(200)       ,XLAM(200)        ,XRAY(500)        ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/  ALK(200)          ,ALPHA(40)        ,BEK(200)
     1 ,BETA(40)       ,DEV(200)         ,DK(200)          ,EK(200)
     2 ,ELAM(200)      ,ELAMAT(20)       ,EMAT(20)         ,ENERGY(200)
     3 ,GAK(200)       ,GAMMA(40)        ,REF(20)          ,SORMAT(20)
     4 ,SUMRAY(200)    ,SUMSOR(200)      ,X(40)            ,XK(200)
     5 ,Y(40)          ,YK(200)          ,Z(40)            ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                     IFLAG(40)        ,IPOINT(50)      ,
     *ISMAX(50)       ,ISOR(20)        ,JF(200)          ,JFL(200)        ,
     *JL(200)         ,JM(200)         ,JN(200)          ,JP(200)         ,
     *JRAY(200)       ,JSOR(50)        ,KBND(900)        ,KFLAG(200)      ,
     *KP(200)         ,KTYP(200)       ,LAMP(50)         ,LANGLE(20)      ,
     *LREFL(200)      ,LTYPE(20)       ,MAT(200)         ,MFL(20)         ,
     *NMAT(20)        ,NUMRAY(200)
      COMMON/PARAMS/          AL        ,ALN       ,ALR       ,ALRF      ,BE       ,
     *BEN       ,BER       ,BERF      ,DIS       ,DMIN      ,DZ        ,EPS      ,
     *GA        ,GAN       ,GAR       ,GARF      ,PER       ,
     *SUMRA     ,XI        ,XNOW      ,XOLD      ,XREF      ,XTRAN     ,YI       ,
     *YNOW      ,YOLD      ,YREF      ,YTRAN     ,ZI        ,
     *ZNOW      ,ZOLD      ,ZREF      ,ZTRAN
      COMMON/IPARAM/          FMAX      ,IMAX      ,INOW      ,
     *IOPRAY    ,IOPRNT    ,IR        ,IRAY      ,JMAX      ,JNOW      ,JOLD     ,
     *KINT      ,KMAX      ,KNOW      ,MMAX      ,NNOW      ,NSOR
      INTEGER F,FMAX
C********** FIND THE COSINE OF THE ANGLE BETWEEN THE RAY AND THE
C********** NORMAL TO THE PLANE
      COSANG=AL*ALK(K)+BE*BEK(K)+GA*GAK(K)
      IF(ABS(COSANG)-1.E-6)103,103,101
C********** CALCULATE THE DISTANCE TO THE POINT OF INTERSECTION.
  101 DHIT=(DK(K)-(ALK(K)*XI+BEK(K)*YI+GAK(K)*ZI))/COSANG
      IF(DHIT)103,104,104
  103 DHIT=1.E21
  104 CONTINUE
      CALL DEBUG(6HINTPLA)
      RETURN
      END
      SUBROUTINE INTSPH(K,DHIT)
C**************************************************************************
C********* INTSPH FINDS THE NEAREST INTERSECTION OF A RAY WITH A SPHERE.
C**************************************************************************
      COMMON /69/        ABCO(20,200)      ,ALRAY(500)       ,BERAY(500)
     1 ,COORDS(6,50)   ,E(40,200)        ,EBASE(200)       ,ESQR(20,200)
     2 ,FARAY(500)     ,REG(20,200)      ,TITLE(12)        ,VMAT(20)
     3 ,VOL(200)       ,XLAM(200)        ,XRAY(500)        ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/   ALK(200)          ,ALPHA(40)        ,BEK(200)
     1 ,BETA(40)       ,DEV(200)         ,DK(200)          ,EK(200)
     2 ,ELAM(200)      ,ELAMAT(20)       ,EMAT(20)         ,ENERGY(200)
     3 ,GAK(200)       ,GAMMA(40)        ,REF(20)          ,SQRMAT(20)
     4 ,SUMRAY(200)    ,SUMSQR(200)      ,X(40)            ,XK(200)
     5 ,Y(40)          ,YK(200)          ,Z(40)            ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                    IFLAG(40)       ,IPOINT(50)     ,
     ,ISMAX(50)     ,ISOR(20)          ,JF(200)         ,JFL(200)       ,
     ,JL(200)       ,JM(200)           ,JN(200)         ,JP(200)        ,
     ,JRAY(200)     ,JSOR(50)          ,KBND(900)       ,KFLAG(200)     ,
     ,KP(200)       ,KTYP(200)         ,LAMP(50)        ,LANGLE(20)     ,
     ,LREFL(200)    ,LTYPE(20)         ,MAT(200)        ,MFL(20)        ,
     ,NMAY(20)      ,NUMRAY(200)
      COMMON/PARAMS/        AL           ,ALN         ,ALR        ,ALOF       ,BE      ,
     ,BEN         ,BER         ,BEOF        ,DIS         ,DMIN       ,DZ         ,EPS     ,
     ,GA          ,GAN         ,GAR         ,GAOF        ,PER        ,
     ,SUMRA       ,XI          ,XNOW        ,XOLD        ,XREF       ,XTRAN      ,YI      ,
     ,YNOW        ,YOLD        ,YREF        ,YTRAN       ,ZI         ,
     ,ZNOW        ,ZOLD        ,ZREF        ,ZTRAN
      COMMON/IPARAM/         FMAX         ,IMAX        ,INCW
     ,IOPRAY      ,IOPRNT      ,IR          ,IRAY        ,JMAX       ,JNOW       ,JOLD    ,
     ,KINT        ,KMAX        ,KNOW        ,MMAX        ,MNOW       ,NSOR
      INTEGER F,FMAX
C********* CALCULATE COEFFICIENTS NEEDED.
      DELX=XI-XK(K)
      DELY=YI-YK(K)
      DELZ=ZI-ZK(K)
      C=DELX**2+DELY**2+DELZ**2-DK(K)**2
      B=DELX*AL+DELY*BE+DELZ*GA
      SQ=B**2-C
      IF(SQ)101,102,102
  102 ROOT=SQRT(SQ)
C********* FIND BOTH ROOTS AND CHOOSE SMALLEST POSITIVE VALUE.
      DHIT1=-B+ROOT
      DHIT2=-B-ROOT
      DHIT=AMIN1(DHIT1,DHIT2)
      IF(DHIT)104,104,105
  104 DHIT=AMAX1(DHIT1,DHIT2)
      IF(DHIT)101,101,105
  101 DHIT=1.E+21
  105 CONTINUE
      CALL DEBUG(6HINTSPH)
      RETURN
      END
      SUBROUTINE JROUND(J)
C.......................................................................
C.......... SUBROUTINE JROUND FINDS THE DISTANCE FROM POINT XI,YI,ZI
C.......... IN THE DIRECTION AL,BE,GA TO EACH OF THE BOUNDARIES OF
C.......... SEGMENT J AND CHOOSES THE SHORTEST POSITIVE DISTANCE.
C.......................................................................
      COMMON /69/        ABCO(20,200)      ,ALRAY(500)       ,BERAY(500)
     1 ,COORDS(6,50)   ,E(40,200)         ,EBASE(200)       ,ESOR(20,200)
     2 ,GARAY(500)     ,RED(20,200)       ,TITLE(12)        ,VMAT(20)
     3 ,VOL(200)       ,XLAM(200)         ,XRAY(500)        ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/  ALK(200)           ,ALPHA(40)        ,BEK(200)
     1 ,BETA(40)       ,DEV(200)          ,DK(200)          ,EK(200)
     2 ,ELAM(200)      ,ELAMAT(20)        ,EMAT(20)         ,ENERGY(2[illegible])
     3 ,GAK(200)       ,GAMMA(40)         ,REF(20)          ,SONMAT(20)
     4 ,SUMRAY(200)    ,SUMSQR(200)       ,X(40)            ,XK(200)
     5 ,Y(40)          ,YK(200)           ,Z(40)            ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                   IFLAG(40)        ,IPOINT(50)      ,
     ,ISMAX(50)      ,ISOR(20)        ,JF(200)         ,JFL(200)        ,
     ,JL(200)        ,JM(200)         ,JN(200)         ,JP(200)         ,
     ,JRAY(200)      ,JSOR(50)        ,KBND(900)       ,KFLAG(200)      ,
     ,KP(200)        ,KTYP(200)       ,LAMP(50)        ,LANGLE(20)      ,
     ,LREFL(200)     ,LTYPE(20)       ,MAT(200)        ,F[illegible]L(20)        ,
     ,NMAT(20)       ,NUMRAY(200)
      COMMON/PARAMS/        AL        ,ALN       ,ALR       ,ALRF      ,BE      ,
     ,BEN       ,BER       ,BERF      ,DIS       ,DMIN      ,UZ        ,EPS     ,
     ,GA        ,GAN       ,GAR       ,GARF      ,PER       ,
     ,SUMRA     ,XI        ,XNOW      ,XOLD      ,XREF      ,XTRAN     ,YI      ,
     ,YNOW      ,YOLD      ,YREF      ,YTRAN     ,ZI        ,
     ,ZNOW      ,ZOLD      ,ZREF      ,ZTRAN
      COMMON/IPARAM/        FMAX      ,IMAX      ,INOW      ,
     ,IOPRAY    ,IOPRNT    ,IR        ,IRAY      ,JMAX      ,JNOW      ,JOLD    ,
     ,KINT      ,KMAX      ,KNOW      ,MMAX      ,MNOW      ,NSOR
      INTEGER F,FMAX
C.......... SET INDEX FOR BOUNDARY ARRAY OF SEGMENT J.
      N=KP(J)
      DIS=1.E20
C.......... CHOOSE A BOUNDARY NUMBER K.
  101 K=IABS(KBND(N))
C.......... IF BOUNDARY HAS ALREADY BEEN CHECKED, GO TO 104.
      IF(KFLAG(K))106,106,104
  106 KFLAG(K)=1
      KT=KTYP(K)
C.......... BRANCH ON BOUNDARY TYPE.
      GO TO(100,200,300,400,500,600,700,800,900),KT
C.......... FIND DISTANCE TO PLANE BOUNDARY NUMBER K.
  100 CALL INTPLA(K,DHIT)
      GO TO 102
C.......... FIND DISTANCE TO CYLINDRICAL BOUNDARY NUMBER K.
  200 CALL INTCYL(K,DHIT)
      GO TO 102
C.......... FIND DISTANCE TO CONICAL BOUNDARY NUMBER K.
  300 CALL INTCON(K,DHIT)
      GO TO 102
C.......... FIND DISTANCE TO SPHERE.
  400 CALL INTSPH(K,DHIT)
      GO TO 102
C.......... FIND DISTANCE TO CONE.
  500 CALL INTCN(K,DHIT)
      GO TO 102
```

```
C********** FIND DISTANCE TO PARABOLOID.
  600 CALL INTPAR(K,DHIT)
      GO TO 102
C********** FIND DISTANCE TO HYPERBOLOID.
  700 CALL INTHYP(K,DHIT)
      GO TO 102
C********** FIND DISTANCE TO ELLIPSOID.
  800 CALL INTELL(K,DHIT)
      GO TO 102
C********** FIND DISTANCE TO HELIX.
  900 CALL INTHEL(K,DHIT)
      GO TO 102
C********** IS DISTANCE LESS THAN MINIMUM DISTANCE.
  102 IF(DHIT-DIS)103,104,104
  103 DIS=DHIT
      KINT=K
C********** LOOK AT NEXT BOUNDARY.
  104 N=N+1
      IF(KBND(N))101,105,101
  105 CONTINUE
      CALL DEBUG(6HJBOUND)
      RETURN
      END
      SUBROUTINE LAMDAT
C.....................................................................
C.......... LAMDAT READS LAMP DATA CARDS.
C.....................................................................
      COMMON /69/       ABCO(20.200)      .ALRAY(500)       .BERAY(500)
     1 .COORDS(6.50)   .E(40.200)        .EBASE(200)       .ESOR(20.200)
     2 .GARAY(500)     .RED(20.200)      .TITLE(12)        .VMAT(20)
     3 .VOL(200)       .XLAM(200)        .XRAY(500)        .YRAY(500)
     4 .ZRAY(500)
      COMMON /ARRAYS/   ALK(200)          .ALPHA(40)        .BEK(200)
     1 .BETA(40)       .DEV(200)         .DK(200)          .EK(200)
     2 .FLAM(200)      .ELAMAT(20)       .EMAT(20)         .ENERGY(200)
     3 .GAK(200)       .GAMMA(40)        .REF(20)          .SORMAT(20)
     4 .SUMRAY(200)    .SUMSOR(200)      .X(40)            .XK(200)
     5 .Y(40)          .YK(200)          .Z(40)            .ZK(200)
     6 .ZLAM(20)
      COMMON/IARRAY/                    IFLAG(40)        .IPOINT(50)      .
     .ISMAX(50)     .ISOR(20)         .JF(200)         .JFL(200)        .
     .JL(200)       .JM(200)          .JN(200)         .JP(200)         .
     .JRAY(200)     .JSOR(50)         .KBND(900)       .KFLAG(200)      .
     .KP(200)       .KTYP(200)        .LAMP(50)        .LANGLE(20)      .
     .LRFFL(200)    .LTYPE(20)        .MAT(200)        .MFL(20)         .
     .NMAT(20)      .NUMRAY(200)
      COMMON/PARAMS/         AL        .ALN       .ALR       .ALRF      .RE      .
     .BEN       .BER       .BERF      .DIS       .DMIN      .DZ        .EPS     .
     .GA        .GAN       .GAN       .GARF      .PER       .
     .SUMRA     .XI        .XNOW      .XOLD      .XREF      .XTRAN     .YI      .
     .YNOW      .YOLD      .YREF      .YTRAN     .ZI        .
     .ZNOW      .ZOLD      .ZREF      .ZTRAN
      COMMON/IPARAM/         FMAX      .IMAX    - .INOW       .
     .IOPRAY    .IOPRNT    .IR        .IRAY      .JMAX      .JNOW      .JOLD    .
     .KINT      .KMAX      .KNOW      .MMAX      .MNOW      .NSOR
      INTEGER F.FMAX
      DIMENSION LAMTAB(10).ISUBT(9).IANGT(9)
      DATA(LAMTAB=6HVOLUME.6HOUTSUM.6HINNSUR.6HRAYINP.6(6H      ))
      DATA(ISUBT=6HINTEN1.6HINTEN2.6HINTEN3.6HINTEN4.
     .6HINTEN5.6HINTEN6.6HINTEN7.6HINTEN8.6HINTEN9)
      DATA(IANGT=6HANGLE1.6HANGLE2.6HANGLE3.6HANGLE4.
     .6HANGLE5.6HANGLE6.6HANGLE7.6HANGLE8.6HANGLE9)
C.......... PRINT PAGE HEADING.
      PRINT 10
   10 FORMAT(1H1.53X.9HLAMP DATA//1H .6H  LAMP.8X.
     .4HLAMP.3X.9HINTENSITY.7X.5HANGLE.3X.9HINTENSITY/
     .1H .6HNUMBER.8X.4HTYPE.5X.7HROUTINE.5X.7HROUTINE/)
C.......... READ A CARD
  100 READ 11.LAMPNO.LAMPT.ISUBI.IANG.ELAMP
   11 FORMAT(I4.3(1X.A6).E12.4)
C.......... LAMP NUMBER =ZERO INDICATES END OF DATA.
      IF(LAMPNO)110.110.101
C.......... PRINT LAMP DATA.
  101 PRINT 12.LAMPNO.LAMPT.ISUBI.IANG.ELAMP
   12 FORMAT(1H .I6.3(6X.A6).E12.4)
C.......... SEARCH TABLE FOR SOURCE TYPE.
      DO 102 N=1.10
      IF(LAMPT-LAMTAB(N))102.104.102
  102 CONTINUE
C.......... SOURCE TYPE NOT IN TABLE.
      CALL ERPRNT(6HLAMDAT)
C.......... STORE SOURCE TYPE INDEX.
  104 ISOR(LAMPNO)=N
C.......... IF MULTIPLE WAVELENGTHS GO TO 106
```

```
      IF(FMAT-1)105.105.106
C.......... STORE SOURCE INTENSITY
  105 ESOR(LAMPNO.I)=ELAMP
      GO TO 107
C.......... SEARCH TABLE FOR NAME OF INTENSITY ROUTINE.
  106 DO 109 IT=1.9
      IF(ISUBI-ISUBT(IT))108.109.108
  108 CONTINUE
C.......... INTENSITY ROUTINE NOT IN TABLE.
      CALL EGPRNT(6HLAMDAT)
C.......... GET INTENSITY AS A FUNCTION OF WAVELENGTH.
  109 CALL INTDAT(IT.LAMPNO)
C.......... IF SURFACE SOURCE. GET NAME OF ANGLE ROUTINE.
  107 IF(ISOR(LAMPNO)-2)111.112.111
  111 IF(ISOR(LAMPNO)-3)113.112.113
  112 DO 114 IA=1.9
      IF(IANG-IANGT(IA))114.115,114
  114 CONTINUE
      CALL EGPRNT(6HLAMDAT)
  115 LANGLE(LAMPNO)=IA
  113 GO TO 100
  110 RETURN
      END
      SUBROUTINE MATDAT
C*********************************************************************
C********** SUBROUTINE MATDAT READS IN MATERIAL DATA FOR EACH MATERIAL.
C*********************************************************************
      COMMON /59/         ABCO(20,200)      ,ALRAY(500)       ,BERAY(500)
     1 ,COORDS(5,50)    ,E(40,200)        ,EBASE(200)       ,ESOR(20,200)
     2 ,GARAY(500)      ,RED(20,200)      ,TITLE(12)        ,VMAT(20)
     3 ,VOL(200)        ,XLAM(200)        ,XRAY(500)        ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/   ALK(200)          ,ALPHA(40)        ,BEK(200)
     1 ,BETA(40)        ,DEV(200)         ,DK(200)          ,EK(200)
     2 ,ELAM(200)       ,ELAMAT(20)       ,EMAT(20)         ,ENERGY(200)
     3 ,GAK(200)        ,GAMMA(40)        ,REF(20)          ,SORMAT(20)
     4 ,SUMRAY(200)     ,SUMSOR(200)      ,X(40)            ,XK(200)
     5 ,Y(40)           ,YK(200)          ,Z(40)            ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                      IFLAG(40)         ,IPOINT(50)       ,
     *ISMAX(50)        ,ISOR(20)          ,JF(200)          ,JFL(200)         ,
     *JL(200)          ,JM(200)           ,JN(200)          ,JP(200)          ,
     *JRAY(200)        ,JSOR(50)          ,KBND(900)        ,KFLAG(200)       ,
     *KP(200)          ,KTYP(200)         ,LAMP(50)         ,LANGLE(20)       ,
     *LREFL(200)       ,LTYPE(20)         ,MAT(200)         ,MFL(20)          ,
     *NMAT(20)         ,NUMRAY(200)
      COMMON/PARAMS/       AL        ,ALM       ,ALR       ,ALRF      ,BE        ,
     *BEA       ,BER       ,BERF      ,DIS       ,DMIN      ,DZ        ,EPS       ,
     *GA        ,GAN       ,GAR       ,GANF      ,PER       ,
     *SUMRA     ,XI        ,XNOW      ,XCLD      ,XREF      ,XTRAN     ,YI        ,
     *YNOW      ,YOLD      ,YREF      ,YTRAN     ,ZI        ,
     *ZNOW      ,ZOLD      ,ZREF      ,ZTRAN
      COMMON/IPARAM/       FMAX      ,IMAX      ,INOW      ,
     *IOPRAY    ,IOPRNT    ,IR        ,IRAY      ,JMAX      ,JNOW      ,JOLD      ,
     *KINT      ,KMAX      ,KNOW      ,MMAX      ,MNOW      ,NSOR
      INTEGER F,FMAX
      DIMENSION DESC(6)
C********** PRINT PAGE HEADING.
      PRINT 9
    9 FORMAT(1H1,55X,13HMATERIAL DATA//9H MATERIAL,4X,5HINPUT,
     *6X,10HABSORPTION,6X,10HREFRACTIVE,10X,6HLASING,
     *5X,11HDESCRIPTION/1H ,8H  NUMBER,2X,7HROUTINE,5X,
     *11HCOEFFICIENT,11X,5HINDEX,6X,10HWAVELENGTH/)
      MMAX=0
C********** READ ONE MATERIAL DATA CARD.
  104 READ 10,M,IAB,ABCOI,REFI,ZLAMI,DESC
   10 FORMAT(I4,1X,A6,3F7.5,6A6)
C********** IF MATERIAL NUMBER IS ZERO, ALL MATERIAL DATA HAS BEEN READ.
      IF(M)103,110,103
C********** IF M GREATER THAN MMAX, MMAX=M.
  103 IF(M-MMAX)102,102,101
  101 MMAX=M
C********** STORE LASING WAVELENGTH AND REFRACTIVE INDEX.
  102 REF(M)=REFI
      ZLAM(M)=ZLAMI
C********** PRINT MATERIAL DATA.
      PRINT 11,M,IAB,ABCOI,REFI,ZLAMI,DESC
   11 FORMAT(1H ,I8,3X,A6,3(4X,F12.6),6X,6A6)
C********** STORE ABSORPTION COEFFICIENT.
      IF(IAB.NE.6H      ) GOTO 106
C********** IF NO WAVELENGTH-DEPENDENT ABSORPTION COEFFICIENT, STORE
C********** CONSTANT VALUE SPECIFIED IN ABCO(M,F).
      DO 105 F=1,FMAX
  105 ABCO(M,F) = ABCOI

      GO TO 104
C********** IF AB. CO. DEPENDS ON WAVELENGTH, GET FROM SUBROUTINE.
  106 CALL ABSORP(IAB,M)
      GO TO 104
  110 CONTINUE
      RETURN
      END
      FUNCTION NINT(S)
C*********************************************************************
C********** NINT FINDS COIL NUMBER IF RAY MOVES DISTANCE S.
C*********************************************************************
      COMMON /69/       ABCO(20,200)        ,ALRAY(500)        ,BERAY(500)
     1 ,COORDS(6,50)   ,E(40,200)           ,EBASE(200)        ,ESOR(20,200)
     2 ,GARAY(500)     ,RED(20,200)         ,TITLE(12)         ,VMAT(20)
     3 ,VOL(200)       ,XLAM(200)           ,XRAY(500)         ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/   ALK(200)            ,ALPHA(40)         ,BEK(200)
     1 ,BETA(40)       ,DEV(200)            ,DK(200)           ,EK(200)
     2 ,ELAM(200)      ,ELAMAT(20)          ,EMAT(20)          ,ENERGY(200)
     3 ,GAK(200)       ,GAMMA(40)           ,REF(20)           ,SORMAT(20)
     4 ,SUMRAY(200)    ,SUMSOR(200)         ,X(40)             ,XK(200)
     5 ,Y(40)          ,YK(200)             ,Z(40)             ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                    IFLAG(40)         ,IPOINT(50)       ,
     *,ISMAX(50)        ,ISOR(20)       ,JF(200)          ,JFL(200)         ,
     *,JL(200)          ,JM(200)        ,JN(200)          ,JP(200)          ,
     *,JRAY(200)        ,JSOR(50)       ,KBND(900)        ,KFLAG(200)       ,
     *KP(200)           ,KTYP(200)      ,LAMP(50)         ,LANGLE(20)       ,
     *LREFL(200)        ,LTYPE(20)      ,MAT(200)         ,MFL(20)          ,
     *NMAT(20)          ,NUMRAY(200)
      COMMON/PARAMS/          AL          ,ALN        ,ALR        ,ALRF       ,BE        ,
     *BEM       ,BER          ,BERF       ,DIS        ,DMIN       ,DZ         ,EPS       ,
     *GA        ,GAM          ,GAR        ,GARF       ,PER        ,
     *SUMRA     ,XI           ,XNOW       ,XOLD       ,XREF       ,XTRAN      ,YI        ,
     *YNOW      ,YOLD         ,YREF       ,YTRAN      ,ZI         ,
     *ZNOW      ,ZOLD         ,ZREF       ,ZTRAN
      COMMON/IPARAM/          FMAX        ,IMAX       ,INOW       ,
     *IOPRAY    ,IOPRNT       ,IR         ,IRAY       ,JMAX       ,JNOW       ,JOLD      ,
     *KINT      ,KMAX         ,KNOW       ,NMAX       ,NNOW       ,NSOR
      INTEGER F,FMAX
      COMMON/HELCOM/A,ABAR,B,BI,BIP,BP,CAP,DELTH,DELX,DELY,DELZ,DMIT,
     *PSIZ,REV,RHO,STH,TH,THI,SORKS,RKS,CSTH,SNTH,RCSTH,RSNTH,BSTH,
     *COSTAN,THZ,DTHZ
      BSD=BE*S-DELY
      ASD=AL*S-DELX
      IF(BSD.EQ.0.0.AND.ASD.EQ.0.0)ASD=1.0
      THST=ATAN2(BSD,ASD)
      NST=IFIX((THST-PSIZ)/REV+1.E+4)-10000
      THZ=THST-NST*REV
      NINT=IFIX((GA*S-DELZ-CAP*THZ)/(CAP*REV)+1.E+4+.5)-10000
      RETURN
      END
      SUBROUTINE NORMAL
C***********************************************************************
C********** SUBROUTINE NORMAL CALCULATES THE NORMAL TO BOUNDARY KNOW.
C***********************************************************************
      COMMON /69/        ABCO(20,200)     ,ALRAY(500)      ,BERAY(500)
     1 ,COORDS(6,50)    ,E(40,200)        ,EBASE(200)      ,ESOM(20,200)
     2 ,GARAY(500)      ,RED(20,200)      ,TITLE(12)       ,VMAT(20)
     3 ,VOL(200)        ,XLAM(200)        ,XRAY(500)       ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/    ALK(200)         ,ALPHA(40)       ,BEK(200)
     1 ,BETA(40)        ,DEV(200)         ,DK(200)         ,EK(200)
     2 ,ELAM(200)       ,ELAMAT(20)       ,EMAT(20)        ,ENERGY(200)
     3 ,GAK(200)        ,GAMMA(40)        ,REF(20)         ,SUMMAT(20)
     4 ,SUMRAY(200)     ,SUMSQR(200)      ,X(40)           ,XK(200)
     5 ,Y(40)           ,YK(200)          ,Z(40)           ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                     IFLAG(40)     ,IPOINT(50)     ,
     *ISMAX(50)      ,ISOR(20)        ,JF(200)      ,JFL(200)       ,
     *JL(200)        ,JM(200)         ,JN(200)      ,JP(200)        ,
     *JRAY(200)      ,JSOR(50)        ,KBND(900)    ,KFLAG(200)     ,
     *KP(200)        ,KTYP(200)       ,LAMP(50)     ,LANGLE(20)     ,
     *LREFL(200)     ,LTYPE(20)       ,MAT(200)     ,MFL(20)        ,
     *NMAT(20)       ,NUMRAY(200)
      COMMON/PARAMS/     AL        ,ALN       ,ALR       ,ALRF      ,BE        ,
     *BEK       ,BER       ,BERF      ,DIS       ,DMIN      ,DZ        ,EPS       ,
     *GA        ,GAN       ,GAR       ,GARF      ,PER       ,
     *SUMRA     ,XI        ,XNOW      ,XOLD      ,XREF      ,XTRAN     ,YI        ,
     *YNOW      ,YOLD      ,YREF      ,YTRAN     ,ZI        ,
     *ZNOW      ,ZOLD      ,ZREF      ,ZTRAN
      COMMON/IPARAM/     FMAX      ,IMAX      ,INOW      ,
     *IOCRAY    ,IOPRNT    ,IR        ,IRAY      ,JMAX      ,JNOW      ,JOLD      ,
     *KINT      ,KMAX      ,KNOW      ,NMAX      ,NNOW      ,NSOR
      INTEGER F,FMAX
      K=KNOW
C********** GET GEOMETRY TYPE FOR BOUNDARY NUMBER K.
      KT=KTYP(K)
C********** BRANCH ON GEOMETRY TYPE.
      GO TO(100,200,300,400,500,600,700,800,900),KT
C********** FIND NORMAL TO PLANE.
  100 CALL PLANOR(K)
      GO TO 101
C********** FIND NORMAL TO CYLINDER.
  200 CALL CYLNOR(K)
      GO TO 101
C********** FIND NORMAL TO CONIC.
  300 CALL CONNOR(K)
      GO TO 101
C********** SPHERE
  400 CALL SPHNOR(K)
      GO TO 101
C********** CONE
  500 CALL CANOR(K)
      GO TO 101
C********** PARABOLOID
  600 CALL PARNOR(K)
      GO TO 101
C********** HYPERBOLOID
  700 CALL HYPNOR(K)
      GO TO 101
C********** ELLIPSOID
  800 CALL ELLNOR(K)

      GO TO 101
C********** HELIX
  900 CALL HELNOR(K)
      GO TO 101
  101 CONTINUE
      CALL DEBUG(6HNORMAL)
      RETURN
      END
      SUBROUTINE PACKUM
C************************************************************************
C********** SUBROUTINE PACKUM PACKS THE RAY ARRAYS TO ELIMINATE THE
C********** STORAGE USED BY RAYS WHICH HAVE BEEN DESTROYED.
C************************************************************************
      COMMON /69/       ABCO(20,200)         ,ALRAY(500)         ,BERAY(500)
     1 ,COORDS(6,50)   ,E(40,200)           ,EBASE(200)         ,ESCR(20,200)
     2 ,GARAY(500)     ,RED(20,200)         ,TITLE(12)          ,VMAT(20)
     3 ,VOL(200)       ,XLAM(200)           ,XRAY(500)          ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/  ALK(200)             ,ALPHA(40)          ,BEK(200)
     1 ,BETA(40)       ,DEV(200)            ,DK(200)            ,EK(200)
     2 ,ELAM(200)      ,ELAMAT(20)          ,EMAT(20)           ,ENERGY(200)
     3 ,GAK(200)       ,GAMMA(40)           ,REF(20)            ,SCRMAT(20) ,
     4 ,SUMRAY(200)    ,SUMSOR(200)         ,X(40)              ,XK(200)
     5 ,Y(40)          ,YK(200)             ,Z(40)              ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                   IFLAG(40)        ,IPOINT(50)      ,
     *ISMAX(50)      ,ISOR(20)         ,JF(200)         ,JFL(200)        ,
     *JL(200)        ,JM(200)          ,JN(200)         ,JP(200)         ,
     *JRAY(200)      ,JSOR(50)         ,KGRD(900)       ,KFLAG(200)      ,
     *KP(200)        ,KTYP(200)        ,LAMP(50)        ,LANGLE(20)      ,
     *LREFL(200)     ,LTYPE(20)        ,MAT(200)        ,MFL(20)         ,
     *MMAT(20)       ,NUMRAY(200)
      COMMON/PARAMS/        AL         ,ALN        ,ALR        ,ALRF       ,BE       ,
     *BEN        ,BER        ,BERF       ,DIS        ,DMIN       ,DZ         ,EPS      ,
     *GA         ,GAN        ,GAR        ,GARF       ,PER        ,
     *SUMRA      ,XI         ,XNOW       ,XOLD       ,XREF       ,XTRAN      ,YI       ,
     *YNOW       ,YOLD       ,YREF       ,YTRAN      ,ZI         ,
     *ZNOW       ,ZOLD       ,ZREF       ,ZTRAN
      COMMON/IPARAM/        FMAX       ,IMAX       ,INOW       ,
     *IOPRAY     ,ICPRNT     ,IR         ,IRAY       ,JMAX       ,JNOW       ,JOLD     ,
     *KINT       ,KMAX       ,KNOW       ,NMAX       ,NNOW       ,NSOR
      INTEGER F,FMAX
C********** SET EFFECTIVE INDEX=1.
      IEF=1
C********** LOOP THROUGH RAY STORAGE.
      DO 100 I=1,IMAX
      IF(IFLAG(I))100,100,101
C********** RE-STORE RAY ON EFFECTIVE INDEX.
  101 ALPHA(IEF)=ALPHA(I)
      BETA(IEF)=BETA(I)
      GAMMA(IEF)=GAMMA(I)
      X(IEF)=X(I)
      Y(IEF)=Y(I)
      Z(IEF)=Z(I)
      DO 103 F=1,FMAX
      E(IEF,F)=E(I,F)
  103 CONTINUE
      IFLAG(IEF)=1
C********** INCREASE EFFECTIVE INDEX BY 1.
      IEF=IEF+1
  100 CONTINUE
      IMAX=IEF-1
      RETURN
      END
      SUBROUTINE PARNOR(K)
C*****************************************************************
C********** PARNOR CALCULATES THE DIRECTIONAL COSINES OF THE NORMAL
C********** TO A POINT ON THE SURFACE OF A PARABOLOID.
C*****************************************************************
      COMMON /69/         ABCO(20,200)     ,ALRAY(500)      ,BERAY(500)
     1 ,CORRCS(6,50)     ,E(40,200)       ,EBASE(200)      ,ESCH(20,200)
     2 ,GARAY(500)       ,RED(20,200)     ,TITLE(12)       ,VMAT(20)
     3 ,VOL(200)         ,XLAM(200)       ,XRAY(500)       ,YHAT(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/     ALK(200)         ,ALPHA(40)       ,BEK(200)
     1 ,BETA(40)         ,DEV(200)        ,DK(200)         ,EK(200)
     2 ,ELAM(200)        ,ELAMAT(20)      ,EMAT(20)        ,ENERGY(200)
     3 ,GAK(200)         ,GAMMA(40)       ,REF(20)         ,SORMAT(20)
     4 ,SUMRAY(200)      ,SUMSOR(200)     ,X(40)           ,XK(200)
     5 ,Y(40)            ,YK(200)         ,Z(40)           ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                      IFLAG(40)      ,IPOINT(50)     ,
     *,ISMAX(50)      ,ISOR(20)        ,JF(200)        ,JFL(200)       ,
     *,JL(200)        ,JM(200)         ,JN(200)        ,JP(200)        ,
     *,JRAY(200)      ,JSOR(50)        ,KBND(900)      ,KFLAG(200)     ,
     *,KP(200)        ,KTYP(200)       ,LAMP(50)       ,LANGLE(20)     ,
     *,LREFL(200)     ,LTYPE(20)       ,MAT(200)       ,MFL(20)        ,
     *,NMAT(20)       ,NUMRAY(200)
      COMMON/PARAMS/       AL        ,ALN       ,ALR       ,ALRF      ,RE        ,
     *,BEN      ,BER       ,BERF      ,DIS       ,DMIN      ,DZ        ,EPS       ,
     *,GA       ,GAN       ,GAR       ,GARF      ,PER       ,
     *,SUMRA    ,XI        ,XNOW      ,XOLD      ,XREF      ,XTRAN     ,YI        ,
     *,YNOW     ,YOLD      ,YREF      ,YTRAN     ,ZI        ,
     *,ZNOW     ,ZOLD      ,ZREF      ,ZTRAN
      COMMON/IPARAM/       FMAX      ,IMAX      ,INOW      ,
     *,IOFRAY   ,IOPRNT    ,IR        ,IRAY      ,JMAX      ,JNOW      ,JOLD      ,
     *,KINT     ,KMAX      ,KNOW      ,MMAX      ,MNOW      ,NSOR
      INTEGER F,FMAX
C********** CALCULATE COEFFICIENTS NEEDED.
      DELX=XNOW-XK(K)
      DELY=YNOW-YK(K)
      DELZ=ZNOW-ZK(K)
C********** CALCULATE LENGTH OF NORMAL VECTOR.
      SQ=SQRT(DELX**2+DELY**2+4.0*DK(K)**2)
C********** CALCULATE DIRECTIONAL COSINES OF NORMAL.
      ALN=DELX/SQ
      BEN=DELY/SQ
      GAN=(-2.0*DK(K))/SQ
C********** CHECK DIRECTIONAL COSINES.
      CALL CHECK(6HPARNOR,ALN,BEN,GAN)
      CALL DEBUG(6HPARNOR)
      RETURN
      END
      SUBROUTINE PERCNT
C*****************************************************************************
C********** SUBROUTINE PERCNT DETERMINES WHAT PERCENT OF THE RAY IS
C********** TRANSMITTED. USES EQUATION FOR DIELECTRICS.
C*****************************************************************************
      COMMON /69/      ABCO(20,200)      ,ALRAY(500)      ,BERAY(500)
     1 ,COORGS(6,50)  ,E(40,200)         ,EBASE(200)      ,ESOR(20,200)
     2 ,GARAY(500)    ,RED(20,200)       ,TITLE(12)       ,VMAT(20)
     3 ,VOL(200)      ,XLAM(200)         ,XRAY(500)       ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/  ALK(200)          ,ALPHA(40)       ,BEK(200)
     1 ,BETA(40)      ,DEV(200)          ,DK(200)         ,EK(200)
     2 ,ELAM(200)     ,ELAMAT(20)        ,EMAT(20)        ,ENERGY(200)
     3 ,GAK(200)      ,GAMMA(40)         ,REF(20)         ,SGRMAT(20)
     4 ,SUMRAY(200)   ,SUMSOR(200)       ,X(40)           ,XK(200)
     5 ,Y(40)         ,YK(200)           ,Z(40)           ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                  IFLAG(40)        ,IPOINT(50)       ,
     *ISMAX(50)       ,ISOR(20)      ,JF(200)          ,JFL(200)         ,
     *JL(200)         ,JM(200)       ,JN(200)          ,JP(200)          ,
     *JRAY(200)       ,JSOR(50)      ,KBND(900)        ,KFLAG(200)       ,
     *KP(200)         ,KTYP(200)     ,LAMP(50)         ,LANGLE(20)       ,
     *LRFFL(200)      ,LTYPE(20)     ,MAT(200)         ,MFL(20)          ,
     *NMAY(20)        ,NUMRAY(200)
      COMMON/PARAMS/          AL          ,ALN        ,ALR        ,ALRF        ,BE        ,
     *BEN        ,BER        ,BERF        ,DIS        ,DMIN        ,DZ        ,EPS        ,
     *GA         ,GAN        ,GAR         ,GARF       ,PER         ,
     *SUMRA      ,XI         ,XNOW        ,XOLD       ,XREF        ,XTRAN     ,YI         ,
     *YNOW       ,YOLO       ,YREF        ,YTRAN      ,ZI          ,
     *ZNOW       ,ZOLO       ,ZREF        ,ZTRAN
      COMMON/IPARAM/          FMAX        ,IMAX       ,INOW        ,
     *IOPRAY     ,IOPRNT     ,IR          ,IRAY       ,JMAX        ,JNOW      ,JOLO       ,
     *KINT       ,KMAX       ,KNOW        ,MMAX       ,MNOW        ,NSOR
      INTEGER F,FMAX
C********** SET INDICES FOR MATERIALS ON EACH SIDE OF BOUNDARY.
      M1=MAT(JOLD)
      M2=MAT(JNOW)
C********** FIND COS OF ANGLE BETWEEN INCOMING RAY AND NORMAL.
      COSA=ABS(AL*ALN+BE*BEN+GA*GAN)
C********** FIND COS OF ANGLE BETWEEN TRANSMITTED RAY AND NORMAL.
      COSB=ABS(ALRF*ALN+BERF*BEN+GARF*GAN)
C********** FIND RATIO OF REFFRACTIVE INDICES.
      EM=REF(M1)/REF(M2)
C********** SOLVE EQUATIONS FOR BOTH MAJOR POLARIZATION AXES(RS,RP).
      RS=((COSB-EM*COSA)/(COSB+EM*COSA))**2
      TMP1=COSA*COSB
      TMP2=EM*(1.0-COSA**2)
      RP=RS*((TMP1-TMP2)/(TMP1+TMP2))**2
C********** FIND PERCENTAGE OF TRANSMISSION.
      PER=1.0-(RS+RP)/2.0
  104 RETURN
      END
      SUBROUTINE PERTRB(AA,BB,GG)
C******************************************************************
C********** PERTRB PERTURBS DIRECTION OF RAY IF NEEDED.
C******************************************************************
      IF(AA**2+BB**2.LT.1.E-7)AA=1.E-3
      IF(GG**2.LT.1.E-7)GG=1.E-3
      P=SQRT(AA**2+BB**2+GG**2)
      AA=AA/P
      BB=BB/P
      GG=GG/P
      RETURN
      END
      SUBROUTINE PLANOR(K)
C***************************************************************************
C******** PLANOR RETRIEVES THE NORMAL TO A PLANE.
C***************************************************************************
       COMMON /69/          ARCO(20,200)       ,ALRAY(500)        ,BERAY(500)
     1 ,COORDS(6,50)      ,E(40,200)          ,EBASE(200)        ,ESUM(20,200)
     2 ,GARAY(500)        ,RED(20,200)        ,TITLE(12)         ,VMAT(20)
     3 ,VOL(200)          ,XLAM(200)          ,XRAY(500)         ,YRAY(500)
     4 ,ZRAY(500)
       COMMON /ARRAYS/      ALK(200)            ,ALPHA(40)         ,BEK(200)
     1 ,BETA(40)          ,DEV(200)           ,DK(200)           ,EK(200)
     2 ,FLAM(200)         ,ELAMAT(20)         ,EMAT(20)          ,ENERGY(200)
     3 ,GAK(200)          ,GAMMA(40)          ,REF(20)           ,SCRMAT(20)
     4 ,SUMRAY(200)       ,SUMSOR(200)        ,X(40)             ,XK(200)
     5 ,Y(40)             ,YK(200)            ,Z(40)             ,ZK(200)
     6 ,ZLAM(20)
       COMMON/IARRAY/                          IFLAG(40)         ,IPOINT(50)      ,
     ,ISMAX(50)        ,ISOR(20)          ,JF(200)          ,JFL(200)        ,
     ,JL(200)          ,JM(200)           ,JN(200)          ,JP(200)         ,
     ,JRAY(200)        ,JSOR(50)          ,KBND(900)        ,KFLAG(200)      ,
     ,KP(200)          ,KTYP(200)         ,LAMP(50)         ,LANGLE(20)      ,
     ,LREFL(200)       ,LTYPE(20)         ,MAT(200)         ,MFL(20)         ,
     ,MMAT(20)         ,NUMRAY(200)
       COMMON/PARAMS/        AL          ,ALN        ,ALR        ,ALRF       ,BE      ,
     ,BEN         ,BER         ,BERF        ,DIS        ,DMIN       ,DZ         ,EPS     ,
     ,GA          ,GAN         ,GAR         ,GARF       ,PER        ,
     ,SUMRA       ,XI          ,XNOW        ,XOLD       ,XREF       ,XTRAN      ,YI      ,
     ,YNOW        ,YOLD        ,YREF        ,YTRAN      ,ZI         ,
     ,ZNOW        ,ZOLD        ,ZREF        ,ZTRAN
       COMMON/IPARAM/         FMAX        ,IMAX       ,INOW       ,
     ,IOARAY      ,IOPRNT      ,IR          ,IRAY       ,JMAX       ,JNOW       ,JOLD    ,
     ,KINT        ,KMAX        ,KNOW        ,MMAX       ,MNOW       ,NSOR
       INTEGER F,FMAX
C********** SET DIRECTIONAL COSINES OF NORMAL TO THE PLANE.
       ALA=ALK(K)
       BEA=BEK(K)
       GAA=GAK(K)
C********** CHECK DIRECTIONAL COSINES.
       CALL CHECK(6HPLANOR,ALA,BEA,GAA)
       CALL DEBUG(6HPLANOR)
       RETURN
       END
      SUBROUTINE POINT(K,ALPT,BEPT,GAPT,XXX,YYY,ZZZ)
C*****************************************************************
C********** POINT LOCATES THE POINT ON THE HELICAL WIRE THAT IS CLOSEST
C********** TO A SPECIFIED POINT AND CALCULATES THE X,Y,Z COMPONENTS OF
C********** THE VECTOR BETWEEN THE TWO POINTS.
C*****************************************************************
      COMMON /69/      ABCD(20,200)      ,ALRAY(500)      ,BERAY(500)
     1 ,COORDS(6,50)  ,E(40,200)         ,EBASE(200)      ,ESON(20,200)
     2 ,GARAY(500)    ,RED(20,200)       ,TITLE(12)       ,VMAT(20)
     3 ,VOL(200)      ,XLAM(200)         ,XRAY(500)       ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/  ALK(200)          ,ALPHA(40)       ,BEK(200)
     1 ,BETA(40)      ,DEV(200)          ,DK(200)         ,EK(200)
     2 ,FLAM(200)     ,ELAMAT(20)        ,EMAT(20)        ,ENERGY(200)
     3 ,GAK(200)      ,GAMMA(40)         ,REF(20)         ,SORMAT(20)
     4 ,SUMRAY(200)   ,SUMSQR(200)       ,X(40)           ,XK(200)
     5 ,Y(40)         ,YK(200)           ,Z(40)           ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                   IFLAG(40)      ,IPOINT(50)     ,
     ,ISMAX(50)    ,ISOR(20)        ,JF(200)       ,JFL(200)       ,
     ,JL(200)      ,JM(200)         ,JN(200)       ,JP(200)        ,
     ,JRAY(200)    ,JSOR(50)        ,KBAD(900)     ,KFLAG(200)     ,
     ,KP(200)      ,KTYP(200)       ,LAMP(50)      ,LANGLE(20)     ,
     ,LREFL(200)   ,LTYPE(20)       ,MAT(200)      ,MFL(20)        ,
     ,NMAT(20)     ,NUMRAY(200)
      COMMON/PARAMS/      AL         ,ALN       ,ALO       ,ALRF      ,BE     ,
     ,BEN      ,BER      ,BERF       ,DIS       ,DMIN      ,DZ        ,EPS    ,
     ,GA       ,GAN      ,GAR        ,GARF      ,PER       ,
     ,SUMRA    ,XI       ,XNOW       ,XOLD      ,XREF      ,XTRAN     ,YI     ,
     ,YNOW     ,YOLD     ,YREF       ,YTRAN     ,ZI        ,
     ,ZNOW     ,ZOLD     ,ZREF       ,ZTRAN
      COMMON/IPARAM/      FMAX       ,IMAX      ,INOW      ,
     ,IOPRAY   ,IOPRNT   ,IR         ,IRAY      ,JMAX      ,JNOW      ,JOLD   ,
     ,KINT     ,KMAX     ,KNOW       ,MMAX      ,MNOW      ,NSOR
      INTEGER F,FMAX
      DATA(TWOPI=6.2831853I)
C********** CALCULATE PARAMETERS NEEDED.
      DELX=XXX-XK(K)
      DELY=YYY-YK(K)
      DELZ=ZZZ-ZK(K)
      PSI=ATAN2(DELY,DELX)
      CAP=ALK(K)
      RHODX=DELX*BEK(K)
      RHODY=DELY*BEK(K)
C********** CALCULATE COIL NUMBER AND STARTING ANGLE(TH).
      NN=IFIX((DELZ-CAP*PSI)/(TWOPI*CAP)+1.E+4+.5)-10000
      TH=PSI+TWOPI*NN
C********** ITERATE UNTIL ANGLE(TH) HAS CONVERGED.
  100 STH=SIN(TH)
      CTH=COS(TH)
      FT=STH*RHODX-CTH*RHODY-CAP*(DELZ-CAP*TH)
      FP=CTH*RHODX+STH*RHODY+CAP**2
      FPP=-STH*RHODX+CTH*RHODY
      IF(ABS(FT*FPP).LT.1.E-4*FP**2)GO TO 102
      DTH=(-FP+FP*SQRT(1.0-2.0*FT*FPP/FP**2))/FPP
      GO TO 103
  102 DTH=-FT/FP
  103 TH=TH+DTH
      IF(ABS(DTH)-1.E-5)101,100,100
C********** CALCULATE X,Y,Z COMPONENTS
  101 ALPT=(DELX-BEK(K)*COS(TH))

      BEPT=(DELY-BEK(K)*SIN(TH))
      GAPT=(DELZ-CAP*TH)
      RETURN
      END
      FUNCTION RAND(MNN)
C*****************************************************************
C********** FUNCTION RAND GENERATES A RANDOM NUMBER BETWEEN 0.0 AND 1.0.
C*****************************************************************
      COMMON/IPARAM/     FMAX      ,IMAX      ,INOW      ,
     *IOPRAY  ,IOPRNT   ,IR        ,IGAY      ,JMAX      ,JNOW      ,JOLD  ,
     *KINT    ,KMAX     ,KNOW      ,MMAX      ,MNOW      ,NSOR
C********** STORE 2**35 - 1 AS CONSTANT
      DATA(J=34359738367)
C********** THE PSEUDO-RANDOM NUMBER IS GENERATED BY THE MIXED CONGRUEN-
C********** TIAL METHOD, USING A PROVED MULTIPLIER AND MODULUS.
C********** FIND IR*5**15 + (1/2-SQRT(3)/6)*2**35 + 1
      I = IR*30517578125 + 7261067067
C********** TURN OFF OVERFLOW INDICATION IF ON
      IF OVERFLOW FAULT 1,1
C********** REDUCE RESULT MODULO 2**35
    1 IR = I .AND. J
C********** FLOAT RESULT
      RIR = IR
C********** MAKE 0 .LE. RESULT .LT. 1
      RAND = RIR/34359738368.
      RETURN
      END
      SUBROUTINE RAY(IFLG)
C***********************************************************************
C********** SUBROUTINE RAY PICKS THE LAST RAY STORED. IF NO RAYS EXIST,
C********** A NEW RAY IS GENERATED.
C***********************************************************************
      COMMON /69/          ABCO(20,200)    ,ALRAY(500)      ,BERAY(500)
     1 ,COORDS(6,50)  ,E(40,200)       ,EBASE(200)      ,ESOR(20,200)
     2 ,GARAY(500)    ,RED(20,200)     ,TITLE(12)       ,VMAT(20)
     3 ,VOL(200)      ,XLAM(200)       ,XRAY(500)       ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/  ALK(200)        ,ALPHA(40)       ,BEK(200)
     1 ,BETA(40)      ,DEV(200)        ,DK(200)         ,EK(200)
     2 ,ELAM(200)     ,ELAMAT(20)      ,EMAT(20)        ,ENERGY(200)
     3 ,GAK(200)      ,GAMMA(40)       ,REF(20)         ,SORMAT(20)
     4 ,SUMRAY(200)   ,SUMSOM(200)     ,X(40)           ,XK(200)
     5 ,Y(40)         ,YK(200)         ,Z(40)           ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                    IFLAG(40)     ,IPOINT(50)      ,
     *ISMAX(50)      ,ISOR(20)        ,JF(200)      ,JFL(200)        ,
     *JL(200)        ,JM(200)         ,JN(200)      ,JP(200)         ,
     *JRAY(200)      ,JSOR(50)        ,KBND(900)    ,KFLAG(200)      ,
     *KP(200)        ,KTYP(200)       ,LAMP(50)     ,LANGLE(20)      ,
     *LREFL(200)     ,LTYPE(20)       ,MAT(200)     ,MFL(20)         ,
     *NMAT(20)       ,NUMRAY(200)
      COMMON/PARAMS/          AL        ,ALN      ,ALR      ,ALRF     ,RE      ,
     *BEN      ,BER      ,BERF      ,DIS      ,DMIN     ,DZ       ,EPS     ,
     *GA       ,GAN      ,GAR       ,GAMF     ,PER      ,
     *SUMRA    ,XI       ,XNOW      ,XOLD     ,XREF     ,XTRAN    ,YI      ,
     *YNOW     ,YOLD     ,YREF      ,YTRAN    ,ZI       ,
     *ZNOW     ,ZOLD     ,ZREF      ,ZTRAN
      COMMON/IPARAM/          FMAX      ,IMAX     ,INOW     ,
     *IOPRAY   ,IOPRNT   ,IR        ,IRAY     ,JMAX     ,JNOW     ,JOLD    ,
     *KINT     ,KMAX     ,KNOW      ,MMAX     ,MNOW     ,NSCR
      INTEGER F,FMAX
      DIMENSION SUMMAT(100)
      DATA(NPAC=0)
C********** IF ARRAY IS FULL, PACK ARRAY.
      IF(IMAX-39)166,167,167
  167 CALL PACKUM
C********** IF ARRAY IS STILL FULL, DESTROY RAY AND PROCEED TO NEXT RAY.
      IF(IMAX-39)166,166,168
  168 PRINT 35,IRAY
   35 FORMAT(1H ,10HRAY NUMBER,I6,33H HAS TOO MANY LEGS. RAY DESTROYED)
C********** SET RAY FLAGS TO 0.
      DO 169 I=1,IMAX
      IFLAG(I)=0
      DO 169 F=1,FMAX
      E(I,F)=0.0
  169 CONTINUE
      IMAX=0
      GO TO 104
C********** EVERY TEN RAYS, PACK THE RAY ARRAYS.
  166 NPAC=NPAC+1
      IF(NPAC-10)102,103,103
  103 CALL PACKUM
      NPAC=0
  102 CONTINUE
C********** IF NO RAYS EXIST IN STORAGE GO TO 104.
      IF(IMAX)104,104,105
C********** LOOK FOR LAST RAY STORED.
  105 DO 100 II=1,IMAX
```

```
      I=IMAX-II+1
      IF(IFLAG(I))100,106,101
  100 CONTINUE
      IMAX=0
C********* GENERATE A NEW RAY.
  104 CALL IRANK
      DO 107 J=1,JMAX
      SUMSQR(J)=SUMSQR(J)+(SUMRAY(J))**2
      ENERGY(J)=ENERGY(J)+SUMRAY(J)
      M=MAT(J)
      IF(M)111,111,112
  112 SUMMAT(M)=SUMMAT(M)+SUMRAY(J)
  111 CONTINUE
      IF(JFL(J))107,107,108
  108 SUMRAY(J)=0.0
      JFL(J)=0
      NUMRAY(J)=NUMRAY(J)+1
  107 CONTINUE
      DO 109 M=1,MMAX
      IF(MFL(M))109,109,110
  110 NMAT(M)=NMAT(M)+1
      SQRMAT(M)=SQRMAT(M)+SUMMAT(M)**2
      MFL(M)=0
  109 SUMMAT(M)=0.0
C********* IF NO RAY EXISTS, SET FLAG AND RETURN.
      IF(IMAX)106,106,105
  106 IFLG=-1
      RETURN
C********* SET PARAMETERS FOR TRACING A NEW RAY.
  101 INOW=1
      JNOW=JOLD
      X1=X(I)
      Y1=Y(I)
      Z1=Z(I)
      XOLD=X1
      YOLD=Y1
      ZOLD=Z1
      AL=ALPHA(I)
      BE=BETA(I)
      GA=GAMMA(I)
      CALL CHECK(6H   RAY,AL,BE,GA)
      IFLG=+1
      CALL DEBUG(6H   RAY)
      RETURN
      END
      SUBROUTINE RAYSOR(ICOUNT)
C*********************************************************************
C******** RAYSOR FETCHES A RAY FROM AN INPUT TABLE.
C*********************************************************************
      COMMON /69/      ABCO(20,200)     ,ALRAY(500)       ,BERAY(500)
     1 ,CHORDS(6,50)   ,E(40,200)       ,EBASE(200)       ,ESOM(20,200)
     2 ,GARAY(500)     ,RED(20,200)     ,TITLE(12)        ,YMAT(20)
     3 ,VOL(200)       ,XLAM(200)       ,XRAY(500)        ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/  ALK(200)         ,ALPHA(40)        ,BEK(200)
     1 ,BETA(40)       ,DEV(200)        ,DK(200)          ,EX(200)
     2 ,ELAM(200)      ,ELAMAT(20)      ,EMAT(20)         ,ENERGY(200)
     3 ,GAK(200)       ,GAMMA(40)       ,REF(20)          ,SUMMAT(20)
     4 ,SUMRAY(200)    ,SUMSUR(200)     ,X(40)            ,XK(200)
     5 ,Y(40)          ,YK(200)         ,Z(40)            ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                    IFLAG(40)       ,IPOINT(50)       ,
     ,ISMAX(50)     ,ISOR(20)        ,JF(200)        ,JFL(200)         ,
     ,JL(200)       ,JM(200)         ,JN(200)        ,JP(200)          ,
     ,JRAY(200)     ,JSOR(50)        ,KBND(900)      ,KFLAG(200)       ,
     ,KP(200)       ,KTYP(200)       ,LAMP(50)       ,LANGLE(20)       ,
     ,LREFL(200)    ,LTYPE(20)       ,MAT(200)       ,MFL(20)          ,
     ,NMAT(20)      ,NUMRAY(200)
      COMMON/PARAMS/       AL          ,ALN        ,ALR        ,ALRF       ,RE     ,
     ,BEL      ,BER        ,BERF       ,DIS        ,DMIN       ,DZ         ,EPS    ,
     ,GA       ,GAN        ,GAR        ,GARF       ,PER        ,
     ,SUMRA    ,XI         ,XNOW       ,XOLD       ,XREF       ,XTRAN      ,YI     ,
     ,YNOW     ,YOLD       ,YREF       ,YTRAN      ,ZI         ,
     ,ZNOW     ,ZOLD       ,ZREF       ,ZTRAN
      COMMON/IPARAM/       FMAX        ,IMAX       ,INOW       ,
     ,IOPRAY   ,IOPRNT     ,IR         ,IRAY       ,JMAX       ,JNOW       ,JOLD   ,
     ,XINT     ,KMAX       ,KNOW       ,MMAX       ,MNOW       ,NSOR
      INTEGER F,FMAX
      IP=IPOINT(MNOW)+ICOUNT-1
      X(IMAX)=XRAY(IP)
      Y(IMAX)=YRAY(IP)
      Z(IMAX)=ZRAY(IP)
      ALPHA(IMAX)=ALRAY(IP)
      BETA(IMAX)=BERAY(IP)
      GAMMA(IMAX)=GARAY(IP)
      CALL CHECK(6HRAYSOR,ALPHA(IMAX),BETA(IMAX),GAMMA(IMAX))
      RETURN
      END
```

```
                                    SUBROUTINE RCYL
C***********************************************************************
C********* RCYL CALCULATES THE INTERSECTION DISTANCE FOR SMALL COSTAN.
C********* PART OF HELIX INTERSECTION CALCULATION.
C***********************************************************************
      COMMON /69/         ABCD(20,200)      ,ALRAY(500)       ,BERAY(500)
     1 ,COORDS(6,50)     ,E(40,200)         ,EBASE(200)       ,ESOR(20,200)
     2 ,GARAY(500)       ,RED(20,200)       ,TITLE(12)        ,VMAT(20)
     3 ,VOL(200)         ,XLAM(200)         ,XRAY(500)        ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/     ALK(200)          ,ALPHA(40)        ,BEK(200)
     1 ,BETA(40)         ,DEV(200)          ,DK(200)          ,EK(200)
     2 ,ELAM(200)        ,ELAMAT(20)        ,EMAT(20)         ,ENERGY(200)
     3 ,GAK(200)         ,GAMMA(40)         ,REF(20)          ,SGMMAT(20)
     4 ,SUMRAY(200)      ,SUMSOR(200)       ,X(40)            ,XK(200)
     5 ,Y(40)            ,YK(200)           ,Z(40)            ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                  IFLAG(40)       ,IPOINT(50)       ,
     *ISMAX(50)       ,ISOR(20)       ,JF(200)        ,JFL(200)         ,
     *JL(200)         ,JM(200)        ,JN(200)        ,JP(200)          ,
     *JRAY(200)       ,JSOR(50)       ,KBND(900)      ,KFLAG(200)       ,
     *KP(200)         ,KTYP(200)      ,LAMP(50)       ,LANGLE(20)       ,
     *LREFL(200)      ,LTYPE(20)      ,MAT(200)       ,NFL(20)          ,
     *NMAT(20)        ,NUMRAY(200)
      COMMON/PARAMS/         AL          ,ALN        ,ALR        ,ALRF        ,BE        ,
     *BEN         ,BER        ,BERF        ,DIS        ,DMIN       ,DZ          ,EPS       ,
     *GA          ,GAN        ,GAR         ,GARF       ,PER        ,
     *SUMRA       ,XI         ,XNOW        ,XOLD       ,XREF       ,XTRAN       ,YI        ,
     *YNOW        ,YOLD       ,YREF        ,YTRAN      ,ZI         ,
     *ZNOW        ,ZOLD       ,ZREF        ,ZTRAN
      COMMON/IPARAM/         FMAX        ,IMAX       ,INOW       ,
     *IOPRAY      ,ICPRNT     ,IR          ,IRAY       ,JMAX       ,JNOW        ,JOLD      ,
     *KINT        ,KMAX       ,KNOW        ,MMAX       ,MNOW       ,NSOR
      INTEGER F,FMAX
      COMMON/HELCOM/A,ABAR,B,B1,B1P,BP,CAP,DELTM,DELX,DELY,DELZ,OMIT,
     *PSIZ,REV,RHO,STM,TM,TMI,SQRKS,RKS,CSTM,SNTM,RCSTM,RSNTM,BSTM,
     *COSTAN,TMZ,DTMZ
      CALL TMOFS
1              CONTINUE
C********** CALCULATE PARAMETERS NEEDED
      XR=STM*AL-DELX-RCSTM
      YR=STM*BE-DELY-RSNTM
      ZR=STM*GA-DELZ-CAP*TM
      FMSQ=XR**2+YR**2+ZR**2
      DOM=(AL*XR+BE*YR+GA*ZR)
      QE=FMSQ-2.0*ABAR
      IF(ABS(QE).LT..001*ABAR) RETURN
      QE=QE/DOM
      QG=(1.-COSTAN**2)/DOM
      DELSTM=QE/(1.+SQRT(1.-QE*QG))
C********** CALCULATE DISTANCE TO INTERSECTION.
      STM=STM-DELSTM
C********** CALCULATE ANGLE TM.
      CALL TMOFS
      GO TO 1
      END
      SUBROUTINE REFDAT
C**********************************************************************
C********** REFDAT READS REFLECTION DATA.
C**********************************************************************
      COMMON /69/         ABCO(20,200)      ,ALRAY(500)        ,BERAY(500)
     1 ,COORDS(6,50)     ,E(40,200)        ,EBASE(250)        ,ESOR(20,200)
     2 ,GARAY(500)       ,RED(20,200)      ,TITLE(12)         ,VMAT(20)
     3 ,VOL(200)         ,XLAM(200)        ,XRAY(500)         ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/     ALK(200)          ,ALPHA(40)         ,BEK(200)
     1 ,BETA(40)         ,DEV(200)         ,DK(200)           ,EK(200)
     2 ,ELAM(200)        ,ELAMAT(20)       ,EMAT(20)          ,ENERGY(200)
     3 ,GAK(200)         ,GAMMA(40)        ,REF(20)           ,SORMAT(20)
     4 ,SUMRAY(200)      ,SUMSOR(200)      ,X(40)             ,XK(200)
     5 ,Y(40)            ,YK(200)          ,Z(40)             ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                  IFLAG(40)          ,IPOINT(50)        ,
     ,ISMAX(50)        ,ISOR(20)      ,JF(200)           ,JFL(200)          ,
     ,JL(200)          ,JM(200)       ,JN(200)           ,JP(200)           ,
     ,JRAY(200)        ,JSOR(50)      ,KBND(900)         ,KFLAG(200)        ,
     ,KP(200)          ,KTYP(200)     ,LAMP(50)          ,LANGLE(20)        ,
     ,LREFL(200)       ,LTYPE(20)     ,MAT(200)          ,MFL(20)           ,
     ,NMAT(20)         ,NUMRAY(200)
      COMMON/PARAMS/           AL          ,ALN        ,ALR        ,ALRF       ,BE      ,
     ,BEN       ,BER         ,BERF        ,DIS        ,DMIN       ,DZ         ,EPS     ,
     ,GA        ,GAN         ,GAR         ,GARF       ,PER        ,
     ,SUMRA     ,XI          ,XNOW        ,XOLD       ,XREF       ,XTRAN      ,YI      ,
     ,YNOW      ,YOLD        ,YREF        ,YTRAN      ,ZI         ,
     ,ZNOW      ,ZOLD        ,ZREF        ,ZTRAN
      COMMON/IPARAM/           FMAX        ,IMAX       ,INOW       ,
     ,IOPRAY    ,IOPRNT      ,IR          ,IGAY       ,JMAX       ,JNOW       ,JOLD    ,
     ,KINT      ,KMAX        ,KNOW        ,MMAX       ,MNOW       ,NSOR
      INTEGER F,FMAX
      DIMENSION LTABLE(10),TEMP(10)
      DATA(LTABLE=6HTABLE ,6HCONST ,6HDIFFUS,6HFUNCT ,6HWAVCAL,
     ,6HWAVIAP,4(6H      ))
C********** PRINT PAGE HEADING.
      PRINT 10
   10 FORMAT(1H1,53X,15HREFLECTION DATA//11H REFLECTION,6X,
     *4HTYPE/11H     NUMBER/)
C********** READ ONE REFLECTION DATA CARD.
  109 READ 11,L,LNAME,TEMP
   11 FORMAT(I4,1X,A6,10F6.4)
C********** REFLECTION NUMBER OF ZERO INDICATES END OF REFLECTION DATA.
      IF(L)110,110,108
  108 LL=L-10
C********** STORE REFLECTION DATA.
      DO 103 N=1,10
  103 RED(LL,N)=TEMP(N)
C********** DETERMINE REFLECTION TYPE.
      DO 104 LT=1,10
      LTYPE(L)=LT
      IF(LNAME-LTABLE(LT))104,105,104
  104 CONTINUE
C********** REFLECTION TYPE NOT IN TABLE.
      CALL ERPRNT(6HREFDAT)
      STOP
  105 IF(LT-5)106,107,106
  106 IF(LT-6)111,112,111
  111 PRINT 13,L,LNAME,TEMP
   13 FORMAT(1H ,I10,4X,A6,10F10.4)


      GO TO 109
  107 PRINT 14,L,LNAME
   14 FORMAT(1H ,I10,4X,A6)
      GO TO 109
C********** GENERATE REFLECTION FRACTIONS AS A FUNCTION OF WAVELENGTH.
  112 CALL REFINP(LL)
      PRINT 15,L,LNAME,(RED(LL,F),F=1,FMAX)
   15 FORMAT(1H ,I10,4X,A6/(1H ,20X,10F10.4))
      GO TO 109
  110 RETURN
      END
      SUBROUTINE REFINP(LL)
C*********************************************************************
C********** REFINP CALLS THE DESIRED ROUTINE FOR GENERATING
C********** REFLECTION FRACTIONS AS A FUNCTION OF WAVELENGTH.
C*********************************************************************
      COMMON /69/        ABCO(20,200)     ,ALRAY(500)      ,BERAY(500)
     1 ,COORCS(6,50)     ,E(40,200)       ,EBASE(200)      ,ESCR(20,200)
     2 ,GARAY(500)       ,RED(20,200)     ,TITLE(12)       ,VMAT(20)
     3 ,VOL(200)         ,XLAM(200)       ,XRAY(500)       ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/    ALK(200)         ,ALPHA(40)       ,BEK(200)
     1 ,BETA(40)         ,DEV(200)        ,DK(200)         ,EK(200)
     2 ,FLAM(200)        ,ELAMAT(20)      ,EMAT(20)        ,ENERGY(200)
     3 ,GAK(200)         ,GAMMA(40)       ,REF(20)         ,SCRMAT(20)
     4 ,SUMRAY(200)      ,SUMSCR(200)     ,X(40)           ,XK(200)
     5 ,Y(40)            ,YK(200)         ,Z(40)           ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                       IFLAG(40)       ,IPOINT(50)      ,
     *,ISMAX(50)      ,ISOR(20)         ,JF(200)         ,JFL(200)        ,
     *,JL(200)        ,JM(200)          ,JN(200)         ,JP(200)         ,
     *,JRAY(200)      ,JSCR(50)         ,KBAC(900)       ,KFLAG(200)      ,
     *,KP(200)        ,KTYP(200)        ,LAMP(50)        ,LANGLE(20)      ,
     *,LREFL(200)     ,LTYPE(20)        ,MAT(200)        ,MFL(20)         ,
     *,NMAT(20)       ,NUMRAY(200)
      COMMON/PARAMS/         AL         ,ALN        ,ALR        ,ALRF       ,RE     ,
     *,BEN       ,BER       ,BERF       ,DIS        ,DMIN       ,DZ         ,EPS    ,
     *,GA        ,GAN       ,GAR        ,GARF       ,PER        ,
     *,SUMRA     ,XI        ,XNOW       ,XCLD       ,XREF       ,XTRAN      ,YI     ,
     *,TNOW      ,YCLO      ,YREF       ,YTRAN      ,ZI         ,
     *,ZNOW      ,ZCLO      ,ZREF       ,ZTRAN      -
      COMMON/IPARAM/         FMAX       ,IMAX       ,INOW       ,
     *,IOPRAY    ,ICPRNT    ,IR         ,IRAY       ,JMAX       ,JNOW       ,JOLD   ,
     *,KINT      ,KMAX      ,KNOW       ,MMAX       ,NNOW       ,NSOR
      INTEGER F,FMAX
      DIMENSION TSTG(200)
      GO TO(100,200,300,400,500,600,700,800,900),LL
  100 CALL REFL11(XLAM,FMAX,TSTG        ,DUM)
      GO TO 110
  200 CALL REFL12(XLAM,FMAX,TSTG        ,DUM)
      GO TO 110
  300 CALL REFL13(XLAM,FMAX,TSTG        ,DUM)
      GO TO 110
  400 CALL REFL14(XLAM,FMAX,TSTG        ,DUM)
      GO TO 110
  500 CALL REFL15(XLAM,FMAX,TSTG        ,DUM)
      GO TO 110
  600 CALL REFL16(XLAM,FMAX,TSTG        ,DUM)
      GO TO 110
  700 CALL REFL17(XLAM,FMAX,TSTG        ,DUM)
      GO TO 110
  800 CALL REFL18(XLAM,FMAX,TSTG        ,DUM)
      GO TO 110
  900 CALL REFL19(XLAM,FMAX,TSTG        ,DUM)
  110 DO 101 F=1,FMAX
      RED(LL,F)=TSTG(F)
  101 CONTINUE
      RETURN
      END
      SUBROUTINE REFLCT
C**********************************************************************
C********** REFLCT CALCULATES THE DIRECTIONAL COSINES OF THE
C********** REFLECTED RAY.
C**********************************************************************
      COMMON /S9/      ABCO(20,200)     ,ALRAY(500)       ,BERAY(500)
     1 ,COORDS(6,50)   ,E(40,200)       ,EBASE(200)       ,ESOR(20,200)
     2 ,FARRAY(500)    ,RED(20,200)     ,TITLE(12)        ,VMAT(20)
     3 ,VOL(200)       ,ULAM(200)       ,XRAY(500)        ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/  ALK(200)         ,ALPHA(40)        ,BEK(200)
     1 ,BETA(40)       ,DEV(200)        ,DK(200)          ,EK(200)
     2 ,ELAM(200)      ,ELAMAT(20)      ,EMAT(20)         ,ENERGY(200)
     3 ,GAK(200)       ,GAMMA(40)       ,REF(20)          ,SORMAT(20)
     4 ,SUMRAY(200)    ,SUMSOR(200)     ,X(40)            ,XK(200)
     5 ,Y(40)          ,YK(200)         ,Z(40)            ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                    IFLAG(40)         ,IPOINT(50)      ,
     ,ISPEX(50)        ,ISOR(20)        ,JF(200)          ,JFL(200)        ,
     ,JL(200)          ,JM(200)         ,JN(200)          ,JP(200)         ,
     ,JRAY(200)        ,JSOR(50)        ,KBND(900)        ,KFLAG(200)      ,
     ,KP(200)          ,KTYP(200)       ,LAMP(50)         ,LANGLE(20)      ,
     ,LREFL(200)       ,LTYPE(20)       ,MAT(200)         ,NFIL(20)        ,
     ,NMAT(20)         ,NUMRAY(200)
      COMMON/PARAMS/          AL           ,ALN         ,ALR         ,ALRF        ,BE      ,
     ,BEN         ,BER         ,BERF        ,DIS         ,DMIN        ,DZ          ,EPS     ,
     ,GA          ,GAN         ,GAR         ,GARF        ,PER         ,
     ,SUMRA       ,XI          ,XNOW        ,XOLD        ,XREF        ,XTRAN       ,YI      ,
     ,YNOW        ,YOLD        ,YREF        ,YTRAN       ,ZI          ,
     ,ZNOW        ,ZOLD        ,ZREF        ,ZTRAN
      COMMON/IPARAM/          FMAX         ,IMAX        ,INOW        ,
     ,IOPRAY      ,IOPRNT      ,IR          ,IRAY        ,JMAX        ,JNOW        ,JOLD    ,
     ,KINT        ,KMAX        ,KNOW        ,NMAX        ,NNOW        ,NSOR
      INTEGER F,FMAX
C********** CALCULATE COEFFICIENT NEEDED.
      BTMP=-2.0*(AL*ALN+BE*BEN+GA*GAN)
C********** CALCULATE COSINES FOR REFLECTED RAY.
      ALR=AL+BTMP*ALN
      BER=BE+BTMP*BEN
      GAR=GA+BTMP*GAN
C********** CHECK DIRECTIONAL COSINES.
      CALL CHECK(6HREFLCT,ALR,BER,GAR)
      CALL DEBUG(6HREFLCT)
      RETURN
      END
      SUBROUTINE REFRAC                                                 ****************
C*****************************************************************************
C********* REFRAC CALCULATE THE DIRECTIONAL COSINES OF THE
C********* REFRACTED(TRANSMITTED) RAY.                     ****************
C*****************************************************************************
      COMMON /69/            ABCO(20,200)          ,ALRAY(500)          ,BERAY(500)
     1 ,COORDS(6,50)         ,E(40,200)            ,EBASE(200)          ,ESCM(20,200)
     2 ,FARAY(500)           ,RED(20,200)          ,TITLE(12)           ,VMAT(20)
     3 ,VEL(200)             ,XLAM(200)            ,XRAY(500)           ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/        ALK(200)              ,ALPHA(40)           ,BEK(200)
     1 ,BETA(40)             ,DEV(200)             ,DK(200)             ,EK(200)
     2 ,ELAM(200)            ,ELAMAT(20)           ,EMAT(20)            ,ENERGY(200)
     3 ,EAK(200)             ,GAMMA(40)            ,REF(20)             ,SCHMAT(20)
     4 ,SUMRAY(200)          ,SUMSQM(200)          ,X(40)               ,XK(200)
     5 ,Y(40)                ,YK(200)              ,Z(40)               ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                          IFLAG(40)           ,IPOINT(50)      ,
     ,ISMAX(50)      ,ISOR(20)                ,JF(200)            ,JFL(200)        ,
     ,JL(200)        ,JM(200)                 ,JN(200)            ,JP(200)         ,
     ,JRAY(200)      ,JSOR(50)                ,KBND(900)          ,KFLAG(200)      ,
     ,KP(200)        ,KTYP(200)               ,LAMP(50)           ,LANGLE(20)      ,
     ,LREFL(200)     ,LTYPE(20)               ,MAT(200)           ,MFL(20)         ,
     ,NMAT(20)       ,NUMRAY(200)                                 ,ALRF       ,RE   ,
      COMMON/PARAMS/           AL          ,ALN          ,ALR      ,DZ         ,EPS  ,
     ,BEN        ,BER          ,BERF       ,DIS          ,DMIN     ,
     ,GA         ,GAN          ,GAR        ,GARF         ,PER      ,XTRAN      ,YI   ,
     ,SUMRA      ,XI           ,XNOW       ,XCLD         ,XREF     ,
     ,YNOW       ,YOLD         ,YREF       ,YTRAN        ,ZI
     ,ZNOW       ,ZOLD         ,ZREF       ,ZTRAN                  ,
      COMMON/IPARAM/            FMAX       ,IMAX         ,INOW     ,JNOW       ,JOLD ,
     ,IOPRAY     ,IOPRNT       ,IR         ,IRAY         ,JMAX     ,NSOR
     ,KINT       ,KMAX         ,KNOW       ,MMAX         ,MNOW
      INTEGER F,FMAX
      REAL LDOTN
      I=INOW
C********* SET INDICES FOR MATERIALS ON EACH SIDE OF BOUNDARY.
      M1=MAT(JOLD)
      M2=MAT(JNOW)
C********* FIND RATIO OF REFRACTIVE INDICES.
      ATMP=REF(M1)/REF(M2)
C********* CALCULATE COEFFICIENTS NEEDED.
  102 LDOTN=AL*ALN+BE*BEN+GA*GAN
C********* IF COSINE OF ANGLE OF INCIDENCE LESS THAN 1.E-6, GO TO 101.
      IF(ABS(LDOTN)-1.E-6)101,101,103
C********* SET DIRECTIONAL COSINES FOR TRANSMITTED RAY.
  101 ALRF=AL
      BERF=BE
      GARF=GA
      PER=1.0
      GO TO 107
  103 BTERM=1.0-(1.0-ATMP**2)/((ATMP**2)*(LDOTN**2))
      IF(BTERM)104,105,105
  104 PER=0.0
C********* IF REFLECTION NUMBER GREATER THAN 10, GO TO 109.
      IF(LREFL(KNOW)-10)107,107,111
  111 ALRF=AL
      BERF=BE
      GARF=GA
      GO TO 109
C********* FRESNEL REFLECTION.
```

```
  105 BTMP=ATMP*LDOTN*(-1.0+SQRT(BTERM))
C********** CALCULATE COSINES OF REFRACTED RAY.
      ALRF=ATMP*AL+BTMP*ALN
      BERF=ATMP*BE+BTMP*BEN
      GARF=ATMP*GA+BTMP*GAN
      CALL CHECK(6HREFRAC,ALRF,BERF,GARF)
  106 IF(LREFL(KNOW)-10)108,108,109
C********** FIND PERCENT OF RAY TO BE TRANSMITTED.
  108 CALL PERCNT
      GO TO 107
C********** GET REFLECTION TYPE(LT).
  109 L=LREFL(KNOW)
      LT=LTYPE(L)
      LL=L-10
C********** BRANCH ON REFLECTION TYPE.
      GO TO(100,200,300,400,500,600),LT
C********** TABLE LOOKUP REFLECTION.
  100 CALL TABREF(LL)
      GO TO 107
C********** CONSTANT REFLECTION.
  200 CALL CONREF(LL)
      GO TO 107
C********** DIFFUSE REFLECTION.
  300 CALL DIFREF(LL)
      GO TO 107
C********** FUNCTION REFLECTION( PERCENT=1.0-A*(1.0+COS(TH)))
  400 CALL FUNREF(LL)
      GO TO 107
  500 CALL WAVREF(LL)
  600 DO 113 F=1,FMAX
      E(IMAX,F)=RED(LL,F)*E(I,F)
      E(I,F)=E(I,F)-E(IMAX,F)
  113 CONTINUE
      GO TO 110
  107 DO 112 F=1,FMAX
      E(IMAX,F)=(1-PER)*E(I,F)
      E(I,F)=PER*E(I,F)
  112 CONTINUE
C********** STORE COSINES OF TRANSMITTED RAY.
  110 ALPHA(I)=ALRF
      BETA(I)=BERF
      GAMMA(I)=GARF
      CALL DEBUG(6HREFRAC)
      RETURN
      END
      SUBROUTINE REVS
C****************************************************************************
C********** PART OF HELIX INTERSECTION CALCULATION.
C****************************************************************************
      COMMON /69/      ABCO(20,200)     ,ALRAY(500)      ,BERAY(500)
     1 ,COORDS(6,50)  ,F(40,200)       ,EBASE(200)      ,ESOR(20,200)
     2 ,GARAY(500)    ,MED(20,200)     ,TITLE(12)       ,XMAT(20)
     3 ,VOL(200)      ,XLAM(200)       ,XRAY(500)       ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/  ALK(200)         ,ALPHA(40)       ,BEK(200)
     1 ,BETA(40)      ,DEV(200)        ,DK(200)         ,EK(200)
     2 ,FLAM(200)     ,ELAMAT(20)      ,EMAT(20)        ,ENERGY(200)
     3 ,GAK(200)      ,GAMMA(40)       ,REF(20)         ,SORMAT(20)
     4 ,SUMRAY(200)   ,SUMSOR(200)     ,X(40)           ,XK(200)
     5 ,Y(40)         ,YK(200)         ,Z(40)           ,ZK(200)
     6 ,ZLAM(20)
      COMMON/TARRAY/                    IFLAG(40)       ,IPOINT(50)      ,
     *ISMAX(50)       ,ISOR(20)        ,JF(200)         ,JFL(200)        ,
     *JL(200)         ,JM(200)         ,JN(200)         ,JP(200)         ,
     *JRAY(200)       ,JSOR(50)        ,KBND(900)       ,KFLAG(200)      ,
     *KP(200)         ,KTYP(200)       ,LAMP(50)        ,LANGLE(20)      ,
     *LREFL(200)      ,LTYPE(20)       ,MAT(200)        ,MFL(20)         ,
     *NMAT(20)        ,NUMRAY(200)
      COMMON/PARAMS/   AL          ,ALN        ,ALR        ,ALRF       ,BE         ,
     *BEN        ,BER        ,BERF       ,DIS        ,DMIN       ,DZ         ,EPS        ,
     *GA         ,GAN        ,GAR        ,GARF       ,PER        ,
     *SUMRA      ,XI         ,XNOW       ,XOLD       ,XREF       ,XTRAN      ,YI         ,
     *YNOW       ,YOLD       ,YREF       ,YTRAN      ,ZI         ,
     *ZNOW       ,ZOLD       ,ZREF       ,ZTRAN
      COMMON/IFAMIN/   FMAX        ,IMAX       ,INOW       ,
     *IORRAY     ,ICPRNT     ,IR         ,IRAY       ,JMAX       ,JNOW       ,JOLD       ,
     *KTNT       ,KMAX       ,KNOW       ,MMAX       ,MNOW       ,NSOR
      INTEGER F,FMAX
      COMMON/HELCOM/A,ABAR,B,B1,B1P,BP,CAP,DELTH,DELX,DELY,DELZ,DHIT,
     *PSTZ,REV,RHO,STH,TH,TH1,SGRAS,RKS,CSTH,SNTH,RCSTH,RSNTH,BSTH,
     *COSTAN,THZ,DTHZ
      IC=0
      IF((B-ABAR)*(B1-ABAR))100,100,101
  100 CALL FINDR
      GO TO 110
  101 IF((B-ABAR)*BP*DELTH)110,104,104
  104 B5=B
      TH5=TH
      B5P=BP
      TH6=TH
      TH4=TH1
      B4=B1
      B4P=B1P
 12               CONTINUE
      DTH=(TH-TH4)/(BP-B4P)*BP
      TH4=TH
      B4=B
       B4P=BP
      TH=TH-DTH
      IF((TH-TH1)*(TH-TH6)) 13,18,18
   18 CONTINUE
      TH=.5*(TH1+TH6)
 13               CONTINUE
      CALL BCALC
      R=(B-ABAR)/(B4-ABAR)
      IF(R) 106,106,19
   19 CONTINUE
      IF(B.LT. 0.5) GO TO 14
      IF(BP*B4P) 14,20,20
   20 CONTINUE
      IF(ABS(TH1-TH6).GT..01) GO TO 14
132              CONTINUE
      TH=TH5
      B=B5
      BP=B5P
          RETURN
14               CONTINUE
      IF(BP*B1P.LT.0) GO TO 15
      TH1=TH
      B1=B
      B1P=BP
      GO TO 16
15               CONTINUE
      TH4=TH
16               CONTINUE
      IC=IC+1
      IF(IC.LT.50) GO TO 12
      PRINT 17, TH,B,BP,TH1,B1,B1P,TH4,B4,B4P,TH5,B5,B5P,TH6
17    FORMAT(9H  REVS 17,/(  12E10.3))
          GO TO 132
  106 CALL FINDR
      TH1=TH
      B1=B
      B1P=BP
      TH=TH5
      B=B5
      BP=B5P
      CALL FINDR
  110 CONTINUE
      RETURN
      END
      SUBROUTINE ROULET(I)
C******************************************************************************
C********* ROULET PLAYS RUSSIAN ROULET WITH RAY NUMBER I.
C******************************************************************************
      COMMON /69/       ABCO(20,200)     ,ALRAY(500)      ,BERAY(500)
     1 ,COORDS(6,50)   ,E(40,200)       ,EBASE(200)      ,ESOR(20,200)
     2 ,GARAY(500)     ,RED(20,200)     ,TITLE(12)       ,VMAT(20)
     3 ,VOL(200)       ,XLAM(200)       ,XRAY(500)       ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/   ALK(200)         ,ALPHA(40)       ,BEK(200)
     1 ,BETA(40)       ,DEV(200)        ,DK(200)         ,EK(200)
     2 ,ELAM(200)      ,ELAMAT(20)      ,EMAT(20)        ,ENERGY(200)
     3 ,FAK(200)       ,GAMMA(40)       ,REF(20)         ,SORMAT(20)
     4 ,SUMRAY(200)    ,SUMSQR(200)     ,X(40)           ,XK(200)
     5 ,Y(40)          ,YK(200)         ,Z(40)           ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                      IFLAG(40)       ,IPOINT(50)     ,
     *ISMAX(50)       ,ISOR(20)         ,JF(200)         ,JFL(200)       ,
     *JL(200)         ,JM(200)          ,JN(200)         ,JP(200)        ,
     *JRAY(200)       ,JSOR(50)         ,KBND(900)       ,KFLAG(200)     ,
     *KP(200)         ,KTYP(200)        ,LAMP(50)        ,LANGLE(20)     ,
     *LREFL(200)      ,LTYPE(20)        ,MAT(200)        ,MFL(20)        ,
     *AMAT(20)        ,NUMRAY(200)
      COMMON/PARAMS/            AL       ,ALN       ,ALR       ,ALRF      ,RE        ,
     *BEA       ,BER      ,BERF     ,DIS       ,DMIN      ,DZ        ,EPS       ,
     *GA        ,GAN      ,GAR      ,GARF      ,PER       ,
     *SUMRA     ,XI       ,XNOW     ,XOLD      ,XREF      ,XTRAN     ,YI        ,
     *YNOW      ,YOLD     ,YREF     ,YTRAN     ,ZI        ,
     *ZNOW      ,ZOLD     ,ZREF     ,ZTRAN
      COMMON/IPARAM/             FMAX     ,IMAX      ,INOW      ,
     *IOPRAY    ,IOPRNT   ,IR       ,IRAY      ,JMAX      ,JNOW      ,JOLD      ,
     *KINT      ,KMAX     ,KNOW     ,MMAX      ,NNOW      ,NSCR
      INTEGER F,FMAX
      COMMON/RASF/  FRAC       ,IDEBUG
  100 DO 101 F=1,FMAX
      IF(E(I,F)-(1.E-6)*EBASE(F))101,101,102
  102 IF(E(I,F)-EBASE(F))103,101,101
  101 CONTINUE
      GO TO 110
  103 RAN=RAND(0)
      IF(RAN-.5)105,104,104
  104 DO 106 F=1,FMAX
      IF(E(I,F)-EBASE(F))107,106,106
  107 E(I,F)=2.0*E(I,F)
  106 CONTINUE
      GO TO 100
  105 DO 108 F=1,FMAX
      IF(E(I,F)-EBASE(F))109,108,108
  109 E(I,F)=0.0
  108 CONTINUE
  110 RETURN
      END
      SUBROUTINE SCALE(M,YLAM,F,SCA)
C*********************************************************************
C********* SCALE CHOOSES A SCALE FACTOR FOR SCALING ENERGY DEPOSITED
C********* FOR A GIVEN WAVELENGTH.
C*********************************************************************
      COMMON /69/      ABCO(20,200)    ,ALRAY(500)      ,BERAY(500)
     1 ,COORDS(6,50)   ,E(40,200)      ,EBASE(200)      ,ESOR(20,200)
     2 ,GARAY(500)     ,RED(20,200)    ,TITLE(12)       ,VMAT(20)
     3 ,VOL(200)       ,XLAM(200)      ,XRAY(500)       ,YRAY(500)
     4 ,ZRAY(500)
                                                         )
      COMMON /ARRAYS/  ALK(200)        ,ALPHA(40)       ,BEK(200)
     1 ,BETA(40)       ,DEV(200)       ,DK(200)         ,EK(200)
     2 ,FLAM(200)      ,ELAMAT(20)     ,EMAT(20)        ,ENERGY(200)
     3 ,GAK(200)       ,GAMMA(40)      ,REF(20)         ,SUMMAT(20)
     4 ,SUMRAY(200)    ,SUMSOR(200)    ,X(40)           ,XK(200)
     5 ,Y(40)          ,YK(200)        ,Z(40)           ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                   IFLAG(40)       ,IPOINT(50)     ,
     ,ISMAX(50)      ,ISOR(20)        ,JF(200)         ,JFL(200)       ,
     ,JL(200)        ,JM(200)         ,JN(200)         ,JP(200)        ,
     ,JRAY(200)      ,JSOR(50)        ,KBND(900)       ,KFLAG(200)     ,
     ,KP(200)        ,KTYP(200)       ,LAMP(50)        ,LANGLE(20)     ,
     ,LABEL(200)     ,LTYPE(20)       ,MAT(200)        ,MFL(20)        ,
     ,NMAT(20)       ,NUMRAY(200)
      COMMON/PARAMS/         AL         ,ALM        ,ALR        ,ALRF       ,BE     ,
     ,BEN        ,BER        ,BERF       ,COS        ,DMIN       ,DZ         ,EPS    ,
     ,GA         ,GAN        ,GAR        ,GARF       ,PER        ,
     ,SUMRA      ,XI         ,XNOW       ,XOLD       ,XREF       ,XTRAN      ,YI     ,
     ,YNOW       ,YOLD       ,YREF       ,YTRAN      ,ZI         ,
     ,ZNOW       ,ZOLD       ,ZREF       ,ZTRAN
      COMMON/IPARAM/         FMAX       ,IMAX       ,INOW       ,
     ,IOPRAY     ,IOPPNT     ,IR         ,IRAY       ,JMAX       ,JNOW       ,JOLD   ,
     ,KOUNT      ,KMAX       ,KNOW       ,MMAX       ,NNOW       ,NSCR
      INTEGER F,FMAX
      DIMENSION YLAM(1)
C********* IF LASING WAVELENGTH IS ZERO, SCALE FACTOR IS ZERO.
      IF(ZLAM(M))100,100,101
  100 SCA=0.0
      GO TO 102
C********* CALCULATE SCALE FACTOR.
  101 SCA=YLAM(F)/ZLAM(M)
  102 RETURN
      END
      SUBROUTINE SEGDAT
C*********************************************************************
C********** SEGDAT READS DATA AND SETS UP SEGMENTS.
C*********************************************************************
      COMMON /69/      ABCD(20,200)     ,ALRAY(500)      ,BERAY(500)
     1 ,COORDS(6,50)  ,E(40,200)        ,EBASE(200)      ,ESOR(20,200)
     2 ,FARAY(500)    ,RED(20,200)      ,TITLE(12)       ,VMAT(20)
     3 ,VOL(200)      ,XLAM(200)        ,XRAY(500)       ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/  ALK(200)         ,ALPHA(40)       ,BEK(200)
     1 ,BETA(40)      ,DEV(200)         ,DK(200)         ,EK(200)
     2 ,ELAM(200)     ,ELAMAT(20)       ,EMAT(20)        ,ENERGY(200)
     3 ,FAK(200)      ,GAMMA(40)        ,REF(20)         ,SGMAT(20)
     4 ,SUMRAY(200)   ,SUMSQR(200)      ,X(40)           ,XK(200)
     5 ,Y(40)         ,YK(200)          ,Z(40)           ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                IFLAG(40)      ,IPOINT(50)     ,
     ,ISMAX(50)      ,ISOR(20)      ,JF(200)       ,JFL(200)       ,
     ,JL(200)        ,JM(200)       ,JN(200)       ,JP(200)        ,
     ,JRAY(200)      ,JSOR(50)      ,KBND(900)     ,KFLAG(200)     ,
     ,KP(200)        ,KTYP(200)     ,LAMP(50)      ,LANGLE(20)     ,
     ,LREFL(200)     ,LTYPE(20)     ,MAT(200)      ,MFL(20)        ,
     ,NMAT(20)       ,NUMRAY(200)
      COMMON/PARAMS/      AL        ,ALN       ,ALR       ,ALRF      ,BE      ,
     ,BEN      ,BER      ,BERF      ,DIS       ,DMIN      ,DZ        ,EPS     ,
     ,GA       ,GAN      ,GAR       ,GARF      ,PER       ,
     ,SUMRA    ,XI       ,XNOW      ,XOLD      ,XREF      ,XTRAN     ,YI      ,
     ,YNOW     ,YOLD     ,YREF      ,YTRAN     ,ZI        ,
     ,ZNOW     ,ZOLD     ,ZREF      ,ZTRAN
      COMMON/IPARAM/      FMAX      ,IMAX      ,INOW      ,
     ,IOPRAY   ,IOPRNT   ,IR        ,IRAY      ,JMAX      ,JNOW      ,JOLD    ,
     ,KINT     ,KMAX     ,KNOW      ,MMAX      ,NNOW      ,NSOR
      INTEGER F,FMAX
      DIMENSION KINPUT(20)
      PRINT 13
      NLP=5
   13 FORMAT(1H1,53X,12HSEGMENT DATA//8H SEGMENT,2X,8HMATERIAL,
     +10X,20HCONFINING BOUNDARIES,53X,6HVOLUME/8H  NUMBER,
     +4X,6HNUMBER/)
      NP=1
      JMAX=0
C********** READ DATA FOR SEGMENT J.
  104 READ 10,J,MATI,(KINPUT(N),N=1,11),VOLI
   10 FORMAT(2I4,11I5,F8.6)
C********** ZERO SEGMENT NUMBER INDICATES END OF DATA.
      IF(J)110,110,103
C********** COUNT NUMBER OF BOUNDARIES FOR SEGMENT J.
  103 DO 105 N=1,11
      IF(KINPUT(N))105,106,105
  105 NB=N
C********** PRINT SEGMENT DATA.
  106 PRINT 12,J,MATI,(KINPUT(N),N=1,11),VOLI
   12 FORMAT(1H ,I7,I10,5X,11I6,6X,F12.6)
C********** IF J GREATER THAN JMAX, JMAX=J.
      IF(J-JMAX)101,101,100
  100 JMAX=J
C********** SET UP SEGMENT J.
  101 KP(J)=NP+1
      MAT(J)=MATI
      VOL(J)=VOLI
      KBND(NP)=0

      DO 102 N=1,NB
      NPT=NP+N
      KBND(NPT)=KINPUT(N)
  102 CONTINUE
      NP=NP+NB+1
      NLP=NLP+1
      IF(NLP-52)107,107,108
  108 NLP=5
      PRINT 13
  107 CONTINUE
      GO TO 104
  110 CONTINUE
      KBND(NP)=0
      RETURN
      END
      SUBROUTINE SEGMNT
C.....................................................................
C.......... SEGMNT FINDS WHICH SEGMENT CONTAINS POINT XI,YI,ZI.
C.....................................................................
      COMMON /69/      AHCO(20,200)     ,ALRAY(500)       ,BERAY(500)
     1 ,COORDS(6,50)   ,E(40,200)       ,EBASE(200)       ,ESCR(20,200)
     2 ,GARAY(500)     ,RED(20,200)     ,TITLE(12)        ,VMAT(20)
     3 ,VOL(200)       ,XLAM(200)       ,XRAY(500)        ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/  ALK(200)         ,ALPHA(40)        ,BEK(200)
     1 ,BETA(40)       ,DEV(200)        ,DK(200)          ,EK(200)
     2 ,FLAM(200)      ,ELAMAT(20)      ,EMAT(20)         ,ENERGY(200)
     3 ,GAK(200)       ,GAMMA(40)       ,REF(20)          ,SCRMAT(20)
     4 ,SUMRAY(200)    ,SUMSQR(200)     ,X(40)            ,XK(200)
     5 ,Y(40)          ,YK(200)         ,Z(40)            ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                    IFLAG(40)       ,IPOINT(50)      ,
     ,ISMAX(50)    ,ISOR(20)         ,JF(200)        ,JFL(200)        ,
     ,JL(200)      ,JM(200)          ,JN(200)        ,JP(200)         ,
     ,JRAY(200)    ,JSOR(50)         ,KBND(900)      ,KFLAG(200)      ,
     ,KP(200)      ,KTYP(200)        ,LAMP(50)       ,LANGLE(20)      ,
     ,LREFL(200)   ,LTYPE(20)        ,MAT(200)       ,MFL(20)         ,
     ,NMAT(20)     ,NUMRAY(200)
      COMMON/PARAMS/        AL          ,ALN        ,ALR        ,ALRF       ,BE   ,
     ,BEN          ,BER     ,BERF       ,DIS        ,DMIN       ,DZ         ,EPS  ,
     ,GA           ,GAN     ,GAR        ,GARF       ,PER        ,
     ,SUMRA        ,XI      ,XNOW       ,XOLD       ,XREF       ,XTRAN      ,YI   ,
     ,YNOW         ,YOLD    ,YREF       ,YTRAN      ,ZI         ,
     ,ZNOW         ,ZOLD    ,ZREF       ,ZTRAN
      COMMON/IPARAM/        FMAX        ,IMAX     - ,INOW       ,
     ,IOPRAY       ,IOPRNT  ,IR         ,IRAY       ,JMAX       ,JNOW       ,JOLD ,
     ,KINT         ,KMAX    ,KNOW       ,MMAX       ,MNOW       ,NSOR
      INTEGER F,FMAX
      JOLD=JNOW
C.......... IF JNOW IS MOTHER SEGMENT NUMBER I, SET J=JNOW.
      IF(JNOW-1)101,100,101
  100 J=JNOW
      GO TO 102
C.......... SET J EQUAL TO MOTHER OF JNOW.
  101 J=JM(JNOW)
C.......... IF POINT IS IN MOTHER SEGMENT NUMBER J, GO TO 104.
  102 IF(INSEG(J))103,103,104
  103 IF(JM(J))105,105,112
  112 J=JM(J)
      GO TO 102
  105 JNOW=0
      GO TO 111
C.......... POINT IS IN MOTHER SEGMENT J.
  104 JNOW=J
C.......... LOOK AT LAST DAUGHTER IN HEIRARCHY.
  106 J=JL(J)
C.......... IF POINT IS IN SEGMENT J, GO TO 110.
  108 IF(INSEG(J))109,109,110
C.......... LOOK AT NEXT LOWER SEGMENT IN HEIRARCHY.
  109 IF(JP(J))111,111,113
  113 J=JP(J)
      GO TO 108
C.......... POINT IS IN SEGMENT J.
  110 JNOW=J
C.......... IF J IS A MOTHER, GO TO 106 AND LOOK AT DAUGHTERS.
      IF(JF(J))111,111,106

  111 CONTINUE
      RETURN
      END
      SUBROUTINE SETCN(K)
C**********************************************************************
C********** SET UP A CONE.
C**********************************************************************
      COMMON /69/        ABCD(20,200)       ,ALRAY(500)        ,BERAY(500)
     1 ,COEFTS(6,50)   ,E(40,200)         ,EBASE(200)        ,ESCN(20,200)
     2 ,GARAY(500)     ,RED(20,200)       ,TITLE(12)         ,[illegible]MAT(20)
     3 ,VOL(200)       ,XLAM(200)         ,XRAY(500)         ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/  ALK(200)           ,ALPHA(40)         ,BEK(200)
     1 ,BETA(40)       ,DEV(200)          ,DK(200)           ,EK(200)
     2 ,ELAM(200)      ,ELAMAT(20)        ,EMAT(20)          ,ENERGY(200)
     3 ,GAK(200)       ,GAMMA(40)         ,REF(20)           ,SGMAT(20)
     4 ,SUMRAY(200)    ,SUMSQM(200)       ,X(40)             ,XK(200)
     5 ,Y(40)          ,YK(200)           ,Z(40)             ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                       IFLAG(40)        ,IPOINT(50)     ,
     ,ISMAX(50)      ,ISUM(20)           ,JF(200)          ,JFL(200)       ,
     ,JL(200)        ,JM(200)            ,JN(200)          ,JP(200)        ,
     ,JRAY(200)      ,JSOR(50)           ,KBNC(900)        ,KFLAG(200)     ,
     ,KP(200)        ,KTYP(200)          ,LAMP(50)         ,LANGLE(20)     ,
     ,LREFL(200)     ,LTYPE(20)          ,MAT(200)         ,MFL(20)        ,
     ,NMAT(20)       ,NUMRAY(200)
      COMMON/PARAMS/          AL         ,ALN        ,ALR        ,ALRF       ,BE      ,
     ,BEN        ,BEM        ,BERF       ,DIS        ,DMIN       ,DZ         ,EPS     ,
     ,GA         ,GAN        ,GAR        ,GARF       ,PER        ,
     ,SUMRA      ,XI         ,XNOW       ,XOLD       ,XREF       ,XTRAN      ,YI      ,
     ,YNOW       ,YOLD       ,YREF       ,YTRAN      ,ZI         ,
     ,ZNOW       ,ZOLD       ,ZREF       ,ZTRAN
      COMMON/IPARAM/          FMAX       ,IMAX       ,INOW       ,
     ,IOARAY     ,IOPRNT     ,IR         ,IRAY       ,JMAX       ,JNOW       ,JOLD    ,
     ,KINT       ,KMAX       ,KNOW       ,MMAX       ,MNOW       ,NSOR
      INTEGER F,FMAX
      COMMON/BNDCOM/BNDPAR(12)
C********** STORE INPUT DATA.
      XK(K)=BNDPAR(1)
      YK(K)=BNDPAR(2)
      ZK(K)=BNDPAR(3)
      EK(K)=BNDPAR(6)-BNDPAR(3)
      DELZ=EK(K)
      DELX=BNDPAR(4)-XK(K)
      DELY=BNDPAR(5)-YK(K)
C********** CALCULATE  COS**2  OF ANGLE FROM CONE AXIS TO CONE SURFACE.
      DK(K)=DELZ**2/(DELX**2+DELY**2+DELZ**2)
C********** PRINT CONE DATA.
      PRINT 11,K,LREFL(K),(BNDPAR(N),N=1,6)
   11 FORMAT(1H ,I5,I6,4X,4HCONE,24X,6F8.3)
      RETURN
      END
      SUBROUTINE SETCON(K)
C**********************************************************************
C********** SETCON SETS UP A CONICAL BOUNDARY FROM THE INPUT DATA FOR
C********** THAT BOUNDARY.
C**********************************************************************
      COMMON /69/        ABCD(20,200)      ,ALRAY(500)       ,BERAY(500)
     1 ,COMPOS(6,50)  ,E(40,200)         ,EBASE(200)        ,ESCN(20,200)
     2 ,GARAY(500)    ,RED(20,200)       ,TITLE(12)         ,VMAT(20)
     3 ,VOL(200)      ,XLAM(200)         ,XRAY(500)         ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/  ALK(200)          ,ALPHA(40)         ,BEK(200)
     1 ,BETA(40)      ,DEV(200)          ,DK(200)           ,EK(200)
     2 ,FLAM(200)     ,ELAMAT(20)        ,EMAT(20)          ,ENERGY(200)
     3 ,GAK(200)      ,GAMMA(40)         ,REF(20)           ,SORMAT(20)
     4 ,SUMRAY(200)   ,SUMSQR(200)       ,X(40)             ,XK(200)
     5 ,Y(40)         ,YK(200)           ,Z(40)             ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                     IFLAG(40)        ,IPOINT(50)      ,
     *,ISMAX(50)    ,ISOR(20)         ,JF(200)         ,JFL(200)        ,
     *,JL(200)      ,JM(200)          ,JN(200)         ,JP(200)         ,
     *,JRAY(200)    ,JSOR(50)         ,KBND(900)       ,KFLAG(200)      ,
     *,KP(200)      ,KTYP(200)        ,LAMP(50)        ,LANGLE(20)      ,
     *,LREFL(200)   ,LTYPE(20)        ,MAT(200)        ,MFL(20)         ,
     *,MMAT(20)     ,NUMRAY(200)
      COMMON/PARAMS/      AL          ,ALN        ,ALR        ,ALRF       ,BE       ,
     *,BEN       ,BER        ,BERF       ,DIS        ,DMIN       ,DZ         ,EPS      ,
     *,GA        ,GAN        ,GAR        ,GARF       ,PER        ,
     *,SUMRA     ,X1         ,XNOW       ,XOLD       ,XREF       ,XTRAN      ,YI       ,
     *,YNOW      ,YOLD       ,YREF       ,YTRAN      ,ZI         ,
     *,ZNOW      ,ZOLD       ,ZREF       ,ZTRAN
      COMMON/IPARAM/      FMAX        ,IMAX       ,INOW       ,
     *,IARRAY    ,IDPANT     ,IN         ,IRAY       ,JMAX       ,JNOW       ,JOLD     ,
     *,KINT      ,KMAX       ,KNOW       ,MMAX       ,MNOW       ,NSOR
      INTEGER F,FMAX
      COMMON/BNDCOM/BNDPAR(12)
C********** STORE BOUNDARY DATA.
      ALK(K)=BNDPAR(1)
      BEK(K)=BNDPAR(2)
      GAK(K)=0.0
      CALL CHECK(6HSETCON,ALK(K),BEK(K),GAK(K))
      XK(K)=BNDPAR(3)
      YK(K)=BNDPAR(4)
      ZK(K)=0.0
C********** CALCULATE ECCENTRICITY AND DISTANCE TO DIRECTRIX.
      DX1=BNDPAR(5)-XK(K)
      DY1=BNDPAR(6)-YK(K)
      R1=SQRT(DX1**2+DY1**2)
      AL1=DX1/R1
      BE1=DY1/R1
      CALL CHECK(6HSETCON,AL1,BE1,0.0)
      TH1=ALK(K)*AL1+BEK(K)*BE1
      DX2=BNDPAR(7)-XK(K)
      DY2=BNDPAR(8)-YK(K)
      R2=SQRT(DX2**2+DY2**2)
      IF(ABS(R1-R2)-1.E-6)100,101,102
  102 AL2=DX2/R2
      BE2=DY2/R2
      CALL CHECK(6HSETCON,AL2,BE2,0.0)
      TH2=ALK(K)*AL2+BEK(K)*BE2
      EK(K)=(R1-R2)/(R1*TH1-R2*TH2)
      DK(K)=(R1*R2*(TH1-TH2))/(R1-R2)

C********** PRINT ARRAY VALUES FOR BOUNDARY.
      PRINT 10,K,LREFL(K),ALK(K),BEK(K),XK(K),YK(K),
     *BNDPAR(5),BNDPAR(6),BNDPAR(7),BNDPAR(8),DK(K),EK(K)
   10 FORMAT(1H ,I5,I6,3X,5HCONIC,2F8.3,8X,2F8.3,8X,
     *6F8.3)
      RETURN
  100 PRINT 12,K
   12 FORMAT(26H INPUT FOR BOUNDARY NUMBER,I6,16H CONTAINS ERRORS)
      STOP
      END
      SUBROUTINE SETCYL(K)
C*****************************************************************************
C********** SETCYL SETS UP A CYLINDRICAL BOUNDARY.
C*****************************************************************************
      COMMON /69/         ABCO(20,200)      ,ALRAY(500)       ,BERAY(500)
     1 ,COORDS(6,50)     ,E(40,200)         ,EBASE(200)       ,ESCH(20,200)
     2 ,GARAY(500)       ,RED(20,200)       ,TITLE(12)        ,VMAT(20)
     3 ,VOL(200)         ,XLAM(200)         ,XRAY(500)        ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/     ALK(200)          ,ALPHA(40)        ,BEK(200)
     1 ,BETA(40)         ,DEV(200)          ,DK(200)          ,EK(200)
     2 ,ELAM(200)        ,ELAMAT(20)        ,EMAT(20)         ,ENERGT(200)
     3 ,GAK(200)         ,GAMMA(40)         ,REF(20)          ,SGRMAT(20)
     4 ,SUMRAY(200)      ,SUMSOR(200)       ,X(40)            ,XK(200)
     5 ,Y(40)            ,YK(200)           ,Z(40)            ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                    IFLAG(40)       ,IPOINT(50)       ,
     *,ISMAX(50)        ,ISOR(20)       ,JF(200)        ,JFL(200)         ,
     *,JL(200)          ,JM(200)        ,JN(200)        ,JP(200)          ,
     *,JRAY(200)        ,JSOR(50)       ,KBND(900)      ,KFLAG(200)       ,
     *,KP(200)          ,KTYP(200)      ,LAMP(50)       ,LANGLE(20)       ,
     *,LREFL(200)       ,LTYPE(20)      ,MAT(200)       ,MFL(20)          ,
     *,NMAT(20)         ,NUMRAY(200)
      COMMON/PARAMS/          AL           ,ALN         ,ALR         ,ALRF        ,RE       ,
     *,BEN        ,BER        ,BERF        ,DIS         ,DMIN        ,DZ          ,EPS      ,
     *,GA         ,GAN        ,GAR         ,GARF        ,PER         ,
     *,SUMRA      ,XI         ,XNOW        ,XOLD        ,XREF        ,XTRAN       ,YI       ,
     *,YNOW       ,YOLD       ,YREF        ,YTRAN       ,ZI          ,
     *,ZNOW       ,ZOLD       ,ZREF        ,ZTRAN
      COMMON/IPARAM/          FMAX         ,IMAX      - ,INOW        ,
     *,IOPRAY     ,IOPRNT     ,IR          ,IRAT        ,JMAX        ,JNOW        ,JOLD     ,
     *,KINT       ,KMAX       ,KNOW        ,MMAX        ,MNOW        ,NSOR
      INTEGER F,FMAX
      COMMON/BNDCOM/BNDPAR(12)
C********** STORE BOUNDARY DATA FOR CYLINDER
      ALK(K)=BNDPAR(1)
      BEK(K)=BNDPAR(2)
      GAK(K)=BNDPAR(3)
C********** CHECK DIRECTIONAL COSINES.
      CALL CHECK(6HSETCYL,ALK(K),BEK(K),GAK(K))
      XK(K)=BNDPAR(4)
      YK(K)=BNDPAR(5)
      ZK(K)=BNDPAR(6)
      DK(K)=BNDPAR(7)
C********** PRINT BOUNDARY DATA.
      PRINT 10,K,LREFL(K),ALK(K),BEK(K),GAK(K),XK(K),YK(K),
     *ZK(K),DK(K)
   10 FORMAT(1H ,I5,I6,2X,6HCYLIND,6F8.3,32X,2F8.3)
      RETURN
      END
      SUBROUTINE SETELL(K)
C****************************************************************
C********* SETELL SETS UP ARRAYS FOR AN ELLIPSOID.
C****************************************************************
      COMMON /69/      ABCD(20,200)      ,ALRAY(500)      ,BERAY(500)
     1 ,CONSTS(6,50)  ,E(40,200)         ,EBASE(200)      ,ESCR(20,200)
     2 ,GARAY(500)    ,RED(20,200)       ,TITLE(12)       ,VMAT(20)
     3 ,VOL(200)      ,XLAM(200)         ,XRAY(500)       ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/  ALK(200)          ,ALPHA(40)       ,BEK(200)
     1 ,BETA(40)      ,DEV(200)          ,DK(200)         ,EK(200)
     2 ,FLAM(200)     ,ELAMAT(20)        ,EMAT(20)        ,ENERGY(200)
     3 ,GAK(200)      ,GAMMA(40)         ,REF(20)         ,SCRMAT(20)
     4 ,SUMRAY(200)   ,SUMSQR(200)       ,X(40)           ,XK(200)
     5 ,Y(40)         ,YK(200)           ,Z(40)           ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                    IFLAG(40)        ,IPOINT(50)      ,
     ,ISMAX(50)       ,ISCR(20)         ,JF(200)         ,JFL(200)        ,
     ,JL(200)         ,JM(200)          ,JN(200)         ,JP(200)         ,
     ,JRAY(200)       ,JSQR(50)         ,KBND(900)       ,KFLAG(200)      ,
     ,KP(200)         ,KTYP(200)        ,LAMP(50)        ,LANGLE(20)      ,
     ,LREFL(200)      ,LTYPE(20)        ,MAT(200)        ,MFL(20)         ,
     ,NMAT(20)        ,NUMRAY(200)
      COMMON/PARAMS/       AL         ,ALN       ,ALR       ,ALRF      ,RE     ,
     ,BEN       ,BER       ,BERF      ,DIS       ,DMIN      ,DZ        ,EPS    ,
     ,GA        ,GAN       ,GAR       ,GARF      ,PER       ,
     ,SUMRA     ,XI        ,XNOW      ,XOLD      ,XREF      ,XTRAN     ,YI     ,
     ,YNOW      ,YOLD      ,YREF      ,YTRAN     ,ZI        ,
     ,ZNOW      ,ZOLD      ,ZREF      ,ZTRAN
      COMMON/IPARAM/       FMAX       ,IMAX    .  ,INOW      ,
     ,IQRAY     ,IQPRNT    ,IR        ,IRAY      ,JMAX .    ,JNOW      ,JOLD   ,
     ,KINT      ,KMAX      ,KNOW      ,MMAX      ,MNOW      ,NSQR
      INTEGER F,FMAX
      COMMON/RNDCOM/RNDPAR(12)
C********* STORE INPUT DATA
      XK(K)=RNDPAR(1)
      YK(K)=RNDPAR(2)
      ZK(K)=RNDPAR(3)
      XI=RNDPAR(4)
      YI=RNDPAR(5)
      ZI=RNDPAR(6)
      ZF=RNDPAR(7)
      SF=ZF-ZK(K)
      AA=2.0*(ZI-ZK(K))*SF-(ZI-ZK(K))**2
      BB=(XI-XK(K))**2+(YI-YK(K))**2
      CC=4.0*SF*(ZI-ZK(K))
C********* SEE IF DATA DESCRIBES AN ELLIPSOID.
      IF(AA-BB)101,101,103
  101 IF(BB-CC)102,102,103
C********* DATA DOES NOT DESCRIBE ELLIPSOID.
  103 PRINT 12,K
   12 FORMAT(1H1,21HDATA FOR BOUNDARY NO.,I6,
     *27H DOES NOT FIT AN ELLIPSOID.)
      STOP
  102 CONTINUE
C********* CALCULATE COEFFICIENTS NEEDED.
      WSQ=(XI-XK(K))**2+(YI-YK(K))**2
      ZST=ZI-ZK(K)
      R=SQRT((ZST-SF)**2+WSQ)*SIGN(1.0,SF)
C********* CALCULATE B.
      EK(K)=(ZST*SF+R)/(4.0+WSQ/(ZST*SF))

C********* CALCULATE A**2.
      DK(K)=EK(K)**2-(EK(K)-SF)**2
C********* PRINT INPUT DATA.
      PRINT 11,K,LREFL(K),(RNDPAR(N),N=1,7)
   11 FORMAT(1H ,I5,I6,2X,6HELLIPS,24X,7F8.3)
      RETURN
      END
      SUBROUTINE SETHEL(K)
C*********************************************************************
C*********************************************************************
      COMMON /69/      ABCD(20,200)       ,ALRAY(500)       ,BERAY(500)
     1 ,COORDS(6,50)   ,E(40,200)         ,EBASE(200)       ,ESCH(20,200)
     2 ,GARAY(500)     ,RED(20,200)       ,TITLE(12)        ,VMAT(20)
     3 ,XPL(200)       ,XLAM(200)         ,XRAY(500)        ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/  ALK(200)           ,ALPHA(40)        ,BEK(200)
     1 ,BETA(40)       ,DEV(200)          ,DK(200)          ,EK(200)
     2 ,ELAM(200)      ,ELAMAT(20)        ,EMAT(20)         ,ENERGY(200)
     3 ,GAK(200)       ,GAMMA(40)         ,REF(20)          ,SUMMAT(20)
     4 ,SUMRAY(200)    ,SUMSQR(200)       ,X(40)            ,XK(200)
     5 ,Y(40)          ,YK(200)           ,Z(40)            ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                     IFLAG(40)       ,IPOINT(50)      ,
     ,ISMAX(50)      ,ISOR(20)          ,JF(200)         ,JFL(200)        ,
     ,JL(200)        ,JM(200)           ,JN(200)         ,JP(200)         ,
     ,JRAY(200)      ,JSOR(50)          ,KBND(900)       ,KFLAG(200)      ,
     ,KP(200)        ,KTYP(200)         ,LAMP(50)        ,LANGLE(20)      ,
     ,LREFL(200)     ,LTYPE(20)         ,MAT(200)        ,MFL(20)         ,
     ,NMAT(20)       ,NUMRAY(200)
      COMMON/PARAMS/      AL         ,ALN        ,ALR        ,ALRF       ,RE      ,
     ,BEN        ,BER        ,BERF       ,DIS        ,DMIN       ,DZ         ,EPS     ,
     ,GA         ,GAN        ,GAR        ,GARF       ,PER        ,
     ,SUMRA      ,XI         ,XNOW       ,XOLD       ,XREF       ,XTRAN      ,YI      ,
     ,YNOW       ,YOLD       ,YREF       ,YTRAN      ,ZI         ,
     ,ZNOW       ,ZOLD       ,ZREF       ,ZTRAN
      COMMON/IPARAM/      FMAX       ,IMAX       ,INOW       ,
     ,IOPRAY     ,IOPRNT     ,IR         ,IRAY       ,JMAX       ,JNOW       ,JOLD    ,
     ,KINT       ,KMAX       ,KNOW       ,MMAX       ,NNOW       ,NSOR
      INTEGER F,FMAX
      COMMON/BNDCOM/BNDPAR(12)
      XK(K)=BNDPAR(1)
      YK(K)=BNDPAR(2)
      ZK(K)=BNDPAR(3)
      ALK(K)=BNDPAR(4)
      BEK(K)=BNDPAR(5)
      DK(K)=BNDPAR(6)
      PRINT 10,K,LREFL(K),(BNDPAR(N),N=1,6)
   10 FORMAT(1H ,I5,I6,2X,6H HELIX,24X,6F8.3)
      RETURN
      END
      SUBROUTINE SETHYP(K)
C•••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
C•••••••••• SETHYP SETS UP THE ARRAYS FOR A HYPERBOLOID.
C•••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
      COMMON /69/      ARCO(20•200)     •ALRAY(500)      •BERAY(500)
     1 •CPCRDS(6•50)   •E(40•200)       •ERASE(200)      •ESOR(20•200)
     2 •GARAY(500)     •RED(20•200)     •TITLE(12)       •VMAT(20)
     3 •VOL(200)       •XLAM(200)       •XRAY(500)       •YRAY(500)
     4 •ZRAY(500)
      COMMON /ARRAYS/  ALK(200)         •ALPHA(40)       •BEK(200)
     1 •BETA(40)       •DEV(200)        •DK(200)         •EK(200)
     2 •FLAM(200)      •ELAMAT(20)      •EMAT(20)        •ENERGY(200)
     3 •GAK(200)       •GAMMA(40)       •REF(20)         •SONMAT(20)
     4 •SUMRAY(200)    •SUMSCR(200)     •X(40)           •XK(200)
     5 •Y(40)          •YK(200)         •Z(40)           •ZK(200)
     6 •ZLAM(20)
      COMMON/IARRAY/                  IFLAG(40)       •IPOINT(50)      •
     •ISMAX(50)      •ISCR(20)        •JF(200)        •JFL(200)        •
     •JL(200)        •JM(200)         •JN(200)        •JP(200)         •
     •JRAY(200)      •JSCR(50)        •KBND(900)      •KFLAG(200)      •
     •KP(200)        •KTYP(200)       •LAMP(50)       •LANGLE(20)      •
     •LREFL(200)     •LTYPE(20)       •MAT(200)       •MFL(20)         •
     •NMAT(20)       •NUMRAY(200)
      COMMON/PARAMS/         AL        •ALN       •ALR       •ALRF      •BE     •
     •HEN       •RER       •BERF      •DIS       •DMIN      •DZ        •EPS    •
     •GA        •GAN       •GAM       •GAMF      •PER       •
     •SUMRA     •XI        •XNOW      •XCLD      •XREF      •XTRAN     •YI     •
     •YNOW      •YOLD      •YREF      •YTRAN     •ZI        •
     •ZNOW      •ZOLD      •ZREF      •ZTRAN
      COMMON/IPARAM/         FMAX      •IMAX      •INOW      •
     •ICPRAY    •ICPRNT    •IR        •IRAY      •JMAX      •JNOW      •JOLD   •
     •KINT      •KMAX      •KNOW      •MMAX      •NNOW      •NSOR
      INTEGER F•FMAX
      COMMON/RNDCOM/RNDPAR(12)
C•••••••••• STORE INPUT DATA.
      XK(K)=RNDPAR(1)
      YK(K)=RNDPAR(2)
      ZK(K)=RNDPAR(3)
      GAK(K)=RNDPAR(7)-ZK(K)
      X1=RNDPAR(4)
      Y1=RNDPAR(5)
      Z1=RNDPAR(6)
      A=4.0•GAK(K)•(Z1-ZK(K))
      B=(X1-XK(K))••2•(Y1-YK(K))••2
C•••••••••• SEE IF DATA DESCRIBES A HYPERBOLOID.
      IF(A-B)101•102•102
  102 PRINT 10•K
   10 FORMAT(1H1•23HDATA FOR BOUNDARY NO.•I6•
     •32HDOES NOT DESCRIBE A HYPERBOLOID.)
      STOP
C•••••••••• CALCULATE COEFFICIENTS NEEDED.
  101 DELX=X1-XK(K)
      DELY=Y1-YK(K)
      WSQ=DELX••2•DELY••2
      ZST=Z1-ZK(K)
      R=SQRT((ZST-GAK(K))••2•WSQ)•SIGN(1.0•ZST)
C•••••••••• CALCULATE AND STORE B.
      EK(K)=(ZST•GAK(K)•R)/(WSQ/(ZST•GAK(K))-4.0)
C•••••••••• CALCULATE AND STORE A••2.
      DK(K)=(EK(K)•GAK(K))••2-EK(K)••2
C•••••••••• PRINT INPUT DATA.
      PRINT 11•K•LREFL(K)•(RNDPAR(N)•N=1•7)
   11 FORMAT(1H •I5•I6•2X•6HHYPERB•24X•7F8.3)
      RETURN
      END
      SUBROUTINE SETPAR(K)
C*********************************************************************
C********** SETPAR SETS UP THE ARRAYS FOR A PARABOLOID.
C*********************************************************************
      COMMON /69/      ABCO(20,200)      ,ALRAY(500)       ,BERAY(500)
     1 ,COORDS(6,50)  ,E(40,200)         ,EBASE(200)       ,ESOM(20,200)
     2 ,GARAY(500)    ,RED(20,200)       ,TITLE(12)        ,VMAT(20)
     3 ,VOL(200)      ,XLAM(200)         ,XRAY(500)        ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/  ALK(200)          ,ALPHA(40)        ,BEK(200)
     1 ,BETA(40)      ,DEV(200)          ,DK(200)          ,EK(200)
     2 ,FLAM(200)     ,ELAMAT(20)        ,EMAT(20)         ,ENERGY(200)
     3 ,GAK(200)      ,GAMMA(40)         ,REF(20)          ,SGRMAT(20)
     4 ,SUMRAY(200)   ,SUMSQR(200)       ,X(40)            ,XK(200)
     5 ,Y(40)         ,YK(200)           ,Z(40)            ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                 IFLAG(40)        ,IPRINT(50)      ,
     ,ISMAX(50)     ,ISOR(20)        ,JF(200)          ,JFL(200)        ,
     ,JL(200)       ,JM(200)         ,JN(200)          ,JP(200)         ,
     ,JRAY(200)     ,JSOR(50)        ,KBND(900)        ,KFLAG(200)      ,
     ,KP(200)       ,KTYP(200)       ,LAMP(50)         ,LANGLE(20)      ,
     ,LREFL(200)    ,LTYPE(20)       ,MAT(200)         ,MFL(20)         ,
     ,NMAT(20)      ,NUMRAY(200)
      COMMON/PARAMS/      AL        ,ALN       ,ALR       ,ALRF      ,BE       ,
     ,BEN      ,BER       ,BERF      ,DIS       ,DMIN      ,DZ        ,EPS      ,
     ,GA       ,GAN       ,GAN       ,GANF      ,PER       ,
     ,SUMRA    ,XI        ,XNOW      ,XOLD      ,XREF      ,XTRAN     ,YI       ,
     ,YNOW     ,YOLD      ,YREF      ,YTRAN     ,ZI        ,
     ,ZNOW     ,ZOLD      ,ZREF      ,ZTRAN
      COMMON/IPARAM/      FMAX      ,IMAX      ,INOW      ,
     ,IOPRAY   ,IOPRNT    ,IR        ,IRAY      ,JMAX      ,JNOW      ,JOLD     ,
     ,KINT     ,KMAX      ,KNOW      ,MMAX      ,NNOW      ,NSOR
      INTEGER F,FMAX
      COMMON/RNDCOM/BNDPAR(12)
C********** STORE INPUT DATA.
      XK(K)=BNDPAR(1)
      YK(K)=BNDPAR(2)
      ZK(K)=BNDPAR(3)
      DK(K)=BNDPAR(4)-ZK(K)
C********** PRINT INPUT DATA.
      PRINT 11,K,LREFL(K),(BNDPAR(N),N=1,4),DK(K)
   11 FORMAT(1H ,I5,I6,3X,5HPARAB,24X,4F8.3,24X,F8.3)
      RETURN
      END
      SUBROUTINE SETPLA(K)
C*************************************************************************
C********** SETPLA SETS UP A PLANE BOUNDARY.
C*************************************************************************
      COMMON /69/       ARCO(20,200)      ,ALRAY(500)       ,BERAY(500)
     1 ,COORDS(6,50)    ,E(40,200)        ,EHASE(200)       ,ESOR(20,200)
     2 ,GARAY(500)      ,RED(20,200)      ,TITLE(12)        ,VMAT(20)
     3 ,VOL(200)        ,XLAM(200)        ,XRAY(500)        ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/   ALK(200)          ,ALPHA(40)        ,BEK(200)
     1 ,BETA(40)        ,DEV(200)         ,DK(200)          ,EK(200)
     2 ,ELAM(200)       ,ELAMAT(20)       ,EMAT(20)         ,ENERGY(200)
     3 ,GAK(200)        ,GAMMA(40)        ,REF(20)          ,SORMAT(20)
     4 ,SUMRAY(200)     ,SUMSOR(200)      ,X(40)            ,XK(200)
     5 ,Y(40)           ,YK(200)          ,Z(40)            ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                      IFLAG(40)         ,IPOINT(50)     ,
     ,ISMAX(50)        ,ISOR(20)          ,JF(200)          ,JFL(200)       ,
     ,JL(200)          ,JM(200)           ,JN(200)          ,JP(200)        ,
     ,JRAY(200)        ,JSOR(50)          ,KBND(900)        ,KFLAG(200)     ,
     ,KP(200)          ,KTYP(200)         ,LAMP(50)         ,LANGLE(20)     ,
     ,LREFL(200)       ,LTYPE(20)         ,MAT(200)         ,MFL(20)        ,
     ,NMAT(20)         ,NUMRAY(200)
      COMMON/PARAMS/          AL          ,ALN        ,ALR        ,ALRF       ,RE      ,
     ,BEK      ,BER        ,BERF          ,DIS        ,DMIN       ,DZ         ,EPS     ,
     ,GA       ,GAN        ,GAR           ,GARF       ,PER        ,
     ,SUMRA    ,XI         ,XNOW          ,XOLD       ,XREF       ,XTRAN      ,YI      ,
     ,YNOW     ,YOLD       ,YREF          ,YTRAN      ,ZI         ,
     ,ZNOW     ,ZOLD       ,ZREF          ,ZTRAN
      COMMON/IPARAM/          FMAX        ,IMAX       ,INOW       ,
     ,IOPRAY   ,IOPRNT     ,IR            ,IRAY       ,JMAX       ,JNOW       ,JOLD    ,
     ,KINT     ,KMAX       ,KNOW          ,MMAX       ,MNOW       ,NSOR
      INTEGER F,FMAX
      COMMON/BNDCOM/BNDPAR(12)
C********** STORE BOUNDARY DATA.
      ALK(K)=BNDPAR(1)
      BEK(K)=BNDPAR(2)
      GAK(K)=BNDPAR(3)
      CALL CHECK(6HSETPLA,ALK(K),BEK(K),GAK(K))
      XK(K)=BNDPAR(4)
      YK(K)=BNDPAR(5)
      ZK(K)=BNDPAR(6)
C********** CALCULATE DISTANCE TO BOUNDARY.
      DK(K)=ALK(K)*XK(K)+BEK(K)*YK(K)+GAK(K)*ZK(K)
C********** IF DISTANCE LESS THAN OR EQUAL TO ZERO, PRINT AND STOP.
      IF(DK(K))101,101,102
  101 PRINT 11,K,DK(K)
   11 FORMAT(1H0,12HBOUNDARY NO.,I6,15H HAS A NEGATIVE,
     ,20H OR ZERO DISTANCE OF,1PE12.4)
      STOP
  102 CONTINUE
C********** PRINT BOUNDARY DATA FOR PLANE.
      PRINT 10,K,LREFL(K),ALK(K),BEK(K),GAK(K),XK(K),YK(K),
     ,ZK(K),DK(K)
   10 FORMAT(1H ,I5,I6,3X,5HPLANE,6F8.3,32X,2F8.3)
      RETURN
      END
      SUBROUTINE SETSPH(K)
C***********************************************************************
C********** SETSPH SETS UP A SPHERICAL BOUNDARY.
C***********************************************************************
      COMMON /69/       ABCO(20,200)      ,ALRAY(500)      ,BERAY(500)
     1 ,COORDS(6,50)   ,E(40,200)         ,EBASE(200)      ,ESOM(20,200)
     2 ,EARAY(500)     ,RED(20,200)       ,TITLE(12)       ,VMAT(20)
     3 ,VOL(200)       ,XLAM(200)         ,XRAY(500)       ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/   ALK(200)          ,ALPHA(40)       ,BEK(200)
     1 ,BETA(40)       ,DEV(200)          ,DK(200)         ,EK(200)
     2 ,ELAM(200)      ,ELAMAT(20)        ,EMAT(20)        ,ENERGY(200)
     3 ,GAK(200)       ,GAMMA(40)         ,REF(20)         ,SGRMAT(20)
     4 ,SUMRAY(200)    ,SUMSOR(200)       ,X(40)           ,XK(200)
     5 ,Y(40)          ,YK(200)           ,Z(40)           ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                      IFLAG(40)        ,IPOINT(50)      ,
     *ISMAX(50)      ,ISOR(20)           ,JF(200)         ,JFL(200)        ,
     *JL(200)        ,JM(200)            ,JN(200)         ,JP(200)         ,
     *JRAY(200)      ,JSOR(50)           ,KBND(900)       ,KFLAG(200)      ,
     *KP(200)        ,KTYP(200)          ,LAMP(50)        ,LANGLE(20)      ,
     *LREFL(200)     ,LTYPE(20)          ,MAT(200)        ,MFL(20)         ,
     *MMAT(20)       ,NUMRAY(200)
      COMMON/PARAMS/          AL          ,ALN        ,ALR        ,ALRF       ,RE        ,
     *BEN        ,BER        ,BERF        ,DIS        ,DMIN       ,DZ         ,EPS       ,
     *GA         ,GAN        ,GAR         ,GAKF       ,PER        ,
     *SUMRA      ,XI       , ,XNOW        ,XOLD       ,XREF       ,XTRAN      ,YI        ,
     *YNOW       ,YOLD       ,YREF        ,YTRAN      ,ZI         ,
     *ZNOW       ,ZOLD       ,ZREF        ,ZTRAN
      COMMON/IPARAM/          FMAX        ,IMAX     - ,INOW       ,
     *IOPRAY     ,IOPRNT     ,IR          ,IRAY       ,JMAX       ,JNOW       ,JOLD      ,
     *KINT       ,KMAX       ,KNOW        ,MMAX       ,MNOW       ,NSOR
      INTEGER F,FMAX
      COMMON/RNDCOM/RNDPAR(12)
C********** STORE INPUT DATA.
      XK(K)=RNDPAR(1)
      YK(K)=RNDPAR(2)
      ZK(K)=RNDPAR(3)
      DK(K)=RNDPAR(4)
C********** PRINT INPUT DATA.
      PRINT 11,K,LREFL(K),XK(K),YK(K),ZK(K),DK(K)
   11 FORMAT(1H ,I5,I6,2X,6HSPHERE,24X,3F8.3,32X,F8.3)
      RETURN
      END
      SUBROUTINE SETUPP
C*********************************************************************
C********** SUBROUTINE SETUPP READS THE INPUT DATA AND HANDLES ALL
C********** SETUP AND PROBLEM INITIALIZATION.
C*********************************************************************
      COMMON /69/     ABCO(20,200)       ,ALRAY(500)       ,BERAY(500)
     1 ,COORDS(6,50)  ,E(40,200)         ,EHASE(200)       ,ESOR(20,200)
     2 ,GARAY(500)    ,RED(20,200)       ,TITLE(12)        ,VMAT(20)
     3 ,VOL(200)      ,XLAM(200)         ,XRAY(500)        ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/  ALK(200)          ,ALPHA(40)        ,BEK(200)
     1 ,BETA(40)      ,DEV(200)          ,DK(200)          ,EK(200)
     2 ,FLAM(200)     ,ELAMAT(20)        ,EMAT(20)         ,ENERGY(200)
     3 ,GAK(200)      ,GAMMA(40)         ,REF(20)          ,SGRMAT(20)
     4 ,SUMRAY(200)   ,SUMSQR(200)       ,X(40)            ,XK(200)
     5 ,Y(40)         ,YK(200)           ,Z(40)            ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                     IFLAG(40)     ,IPCINT(50)      ,
     *ISMAX(50)     ,ISOR(20)          ,JF(200)       ,JFL(200)        ,
     *JL(200)       ,JM(200)           ,JN(200)       ,JP(200)         ,
     *JRAY(200)     ,JSOR(50)          ,KBND(900)     ,KFLAG(200)      ,
     *KP(200)       ,KTYP(200)         ,LAMP(50)      ,LANGLE(20)      ,
     *LREFL(200)    ,LTYPE(20)         ,MAT(200)      ,MFL(20)         ,
     *NMAT(20)      ,NUMRAY(200)
      COMMON/PARAMS/       AL          ,ALN        ,ALR        ,ALRF        ,RE     ,
     *BEN        ,BER        ,BERF       ,DIS        ,DMIN       ,DZ          ,EPS    ,
     *GA         ,GAN        ,GAR        ,GARF       ,PER        ,
     *SUMRA      ,X1         ,XNOW       ,XCLD       ,XREF       ,XTRAN       ,Y1     ,
     *YNOW       ,YOLD       ,YREF       ,YTRAN      ,ZI         ,
     *ZNOW       ,ZOLD  .    ,ZREF       ,ZTRAN  .
      COMMON/IPARAM/       FMAX        ,IMAX       ,INOW       ,
     *IORRAY     ,IOPRNT     ,IR         ,IRAY       ,JMAX       ,JNOW        ,JOLD   ,
     *KINT       ,KMAX       ,KNOW       ,MMAX       ,MNOW       ,NSOR
      INTEGER F,FMAX
      COMMON/PHASE/  FRAC       ,IDEBUG
C********** INITIALIZE PARAMETERS.
      IRAY=0
      JOLD=1
      EPS=1.E-3
      SUMRA=0.0
      IMAX=0
      PRINT 12
   12 FORMAT(1H1,21HGENERAL INPUT FOR ZAP//)
C********** READ INPUT DATA.
      READ 10,TITLE
   10 FORMAT(12A6)
      READ 11,FRAC,DZ,WAVMIN,WAVMAX
   11 FORMAT(6E12.4)
      READ 15,FMAX,IOPRNT,IDEBUG,IR
   15 FORMAT(3I6,I16)
C********** IF MULTIPLE WAVELENGTHS, CALCULATE AND STORE THEM.
      IF(FMAX-1)109,110,111
  109 FMAX=1
      GO TO 110
  111 DF=(WAVMAX-WAVMIN)/(FMAX-1)
      WAVF=WAVMIN
      DO 112 F=1,FMAX
      XLAM(F)=WAVF
      WAVF=WAVF+DF
  112 CONTINUE
      GO TO 113
  110 XLAM(1)=WAVMIN
  113 CONTINUE
      IF(FRAC) 105.105.107
  105 FRAC=.5
  107 CONTINUE
      PRINT 13.TITLE
   13 FORMAT(1H0.12A6//)
      PRINT 14.FRAC.DZ.WAVMIN.WAVMAX.FMAX.IOPRNT.IDEBUG.IR
   14 FORMAT(1H .18HROULETTE FRACTION=.E12.4/
     .42H DISTANCE BETWEEN CONTINUITIVE BOUNDARIES=.E12.4/
     .20H MINIMUM WAVELENGTH=.E12.4/
     .20H MAXIMUM WAVELENGTH=.E12.4/
     .23H NUMBER OF WAVELENGTHS=.I6/
     .18H RAY PRINT OPTION=.I6/20H DEBUG PRINT OPTION=.I6/
     .25H STARTING RANDOM INTEGER=.I16)
C.......... READ REFLECTION DATA
  100 CALL REFDAT
C.......... READ MATERIAL DATA AND SET UP MATERIAL ARRAYS.
      CALL MATDAT
C.......... READ BOUNDARY DATA AND SET UP BOUNDARY ARRAYS.
      CALL BNDDAT
C.......... READ SEGMENT DATA AND SET UP SEGMENT ARRAYS.
      CALL SEGDAT
C.......... READ STRUCTURE DATA AND SET UP SEGMENT STRUCTURE.
      CALL STRUCT
C.......... READ LAMP DATA AND SET UP LAMP ARRAYS.
      CALL LAMDAT
C.......... READ SOURCE DATA.
      CALL SCRDAT
C.......... READ TEST POINT DATA AND TEST SETUP.
      CALL TEST
C.......... GENERATE PRINTER PLOTS OF GEOMETRY.
      CALL GEOPLT
      CALL DEBUG(6HSETUPP)
      RETURN
      END
```

```
                                   SUBROUTINE SOFTH
C*************************************************************************
C********** SOFTH CALCULATES STH AND BSTH.
C********** PART OF HELIX INTERSECTION CALCULATION.
C*************************************************************************
      COMMON /69/       ABCO(20,200)        ,ALRAY(500)         ,BERAY(500)
     1 ,COORDS(6,50)   ,E(40,200)          ,EBASE(200)         ,ESOM(20,200)
     2 ,GARAY(500)     ,RED(20,200)        ,TITLE(12)          ,VMAT(20)
     3 ,VOL(200)       ,XLAM(200)          ,XRAY(500)          ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/   ALK(200)            ,ALPHA(40)          ,BEK(200)
     1 ,BETA(40)       ,DEV(200)           ,DK(200)            ,EK(200)
     2 ,FLAM(200)      ,ELAMAT(20)         ,EMAT(20)           ,ENERGY(200)
     3 ,GAK(200)       ,GAMMA(40)          ,REF(20)            ,SOMMAT(20)
     4 ,SUMRAY(200)    ,SUMSQR(200)        ,X(40)              ,XK(200)
     5 ,Y(40)          ,YK(200)            ,Z(40)              ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                   IFLAG(40)        ,IPOINT(50)      ,
     *ISMAX(50)      ,ISOR(20)         ,JF(200)         ,JFL(200)        ,
     *JL(200)        ,JM(200)          ,JN(200)         ,JP(200)         ,
     *JRAY(200)      ,JSOR(50)         ,KBND(900)       ,KFLAG(200)      ,
     *KP(200)        ,KTYP(200)        ,LAMP(50)        ,LANGLE(20)      ,
     *LREFL(200)     ,LTYPE(20)        ,MAT(200)        ,MFL(20)         ,
     *NMAT(20)       ,NUMRAY(200)
      COMMON/PARAMS/        AL          ,ALN         ,ALR         ,ALRF        ,RE      ,
     *BEN        ,BER        ,BERF        ,DIS         ,DMIN        ,DZ          ,EPS     ,
     *GA         ,GAN        ,GAR         ,GARF        ,PER         ,
     *SUMRA      ,XI         ,XNOW        ,XOLD        ,XREF        ,XTRAN       ,YI      ,
     *YNOW       ,YOLD       ,YREF        ,YTHAN       ,ZI          ,
     *ZNOW       ,ZOLD       ,ZREF        ,ZTHAN
      COMMON/IPARAM/        FMAX        ,IMAX        ,INOW        ,
     *IOPRAY     ,IOPRNT     ,IR          ,IRAY        ,JMAX        ,JNOW        ,JOLD    ,
     *KINT       ,KMAX       ,KNOW        ,MMAX        ,MNOW        ,NSOM
      INTEGER F,FMAX
      COMMON/HELCOM/A,ABAM,B,B1,B1P,BP,CAP,DELTH,DELX,DELY,DELZ,DHIT,
     *PSIZ,REV,RHO,STH,TH,TH1,SQRKS,RKS,CSTH,SNTH,RCSTH,RSNTH,BSTH,
     *COSTAN,THZ,DTHZ
      STH=AL*(DELX*HCSTH)+BE*(DELT*RSNTH)+GA*(DELZ*CAP*TH)
      BSTH=(DELX+RCSTH-AL*STH)**2+(DELY+RSNTH-BE*STH)**2
     *     +(DELZ+CAP*TH-GA*STH)**2
      RETURN
      END
      SUBROUTINE SORDAT
C*****************************************************************************
C********** SORDAT READS SOURCE DATA CARDS AND SETS UP SOURCES.
C*****************************************************************************
      COMMON /69/          ABCO(20,200)        ,ALRAY(500)          ,BEMAY(500)
     1 ,COORDS(6,50)       ,E(40,200)          ,EBASE(200)          ,ESOM(20,200)
     2 ,FARAY(500)         ,RED(20,200)        ,TITLE(12)           ,VMAT(20)
     3 ,VOL(200)           ,XLAM(200)          ,XRAY(500)           ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/      ALK(200)            ,ALPHA(40)           ,BEK(200)
     1 ,BETA(40)           ,DEV(200)           ,DK(200)             ,EK(200)
     2 ,ELAM(200)          ,ELAMAT(20)         ,EMAT(20)            ,ENERGY(200)
     3 ,GAK(200)           ,GAMMA(40)          ,REF(20)             ,SOMAT(20)
     4 ,SUMRAY(200)        ,SUMSOR(200)        ,X(40)               ,XK(200)
     5 ,Y(40)              ,YK(200)            ,Z(40)               ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                        IFLAG(40)          ,IPOINT(50)        ,
     ,ISMAX(50)      ,ISOR(20)         ,JF(200)           ,JFL(200)          ,
     ,JL(200)        ,JM(200)          ,JN(200)           ,JP(200)           ,
     ,JRAY(200)      ,JSOR(50)         ,KBND(900)         ,KFLAG(200)        ,
     ,KP(200)        ,KTYP(200)        ,LAMP(50)          ,LANGLE(20)        ,
     ,LREFL(200)     ,LTYPE(20)        ,MAT(200)          ,MFL(20)           ,
     ,NMAT(20)       ,NUMRAY(200)
      COMMON/PARAMS/          AL          ,ALN         ,ALR         ,ALRF        ,RE     ,
     ,BEN        ,BER         ,BERF        ,DIS         ,DMIN        ,DZ          ,EPS    ,
     ,GA         ,GAN         ,GAR         ,GARF        ,PER         ,
     ,SUMRA      ,X1          ,XNGW        ,XOLD        ,XREF        ,XTRAN       ,YI     ,
     ,YNOW       ,YOLD        ,YREF        ,YTRAN       ,Z1          ,
     ,ZNOW       ,ZOLD        ,ZREF        ,ZTRAN
      COMMON/IPARAM/          FMAX        ,IMAX        ,INOW        ,
     ,IOPRAY     ,IOPRNT      ,IR          ,IRAY        ,JMAX        ,JNOW        ,JOLD   ,
     ,KINT       ,KMAX        ,KNOW        ,MMAX        ,NNOW        ,NSOR
      INTEGER F,FMAX
      DIMENSION TEMP(6)
      DATA(IF=1)
C********** PRINT PAGE HEADING.
      PRINT 9
    9 FORMAT(1H1,53X,11HSOURCE DATA//1H ,6HSOURCE,3X,7HSEGMENT,
     ,2X,8HBOUNDARY,6X,4HLAMP,4X,6HNUMBER,4X,
     ,21HGEOMETRIC SOURCE DATA/1H ,6HNUMBER,4X,6HNUMBER,
     ,4X,6HNUMBER,4X,6HNUMBER,3X,7HOF RAYS/)
      NSOR=0
C********** READ A SOURCE DATA CARD.
  112 READ 12,N,JKSOR,LAMPN,ISMAXI,TEMP
   12 FORMAT(3I4,I5,6F8.3)
C********** N=0 INDICATES END OF SOURCE DATA.
      IF(N)111,111,100
C********** RETRIEVE SOURCE TYPE.
  100 ISORR=ISOR(LAMPN)
C********** BRANCH ON SOURCE TYPE.
      GO TO(101,102,102,104),ISORR
C********** VOLUME SOURCE
  101 NBND=0
      NSEG=JKSOR
      GO TO 103
C********** SURFACE SOURCE
  102 NBND=JKSOR
      NSEG=0
      GO TO 103
C********** RAY INPUT SOURCE
  104 NBND=0
```

```
      NSEG=0
C••••••••• PRINT SOURCE DATA
  103 PRINT 13,N,NSEG,NBND,LAMPN,ISMAXI,TEMP
   13 FORMAT(1H ,I6,4I10,6F12.5)
C••••••••• IF N GREATER THAN NSOR, NSOR=N
      IF(N-NSOR)106,106,107
  107 NSOR=N
C••••••••• STORE SOURCE DATA.
  106 JSOR(N)=JKSOR
      ISMAX(N)=ISMAXI
      LAMP(N)=LAMPN
C••••••••• IF RAYS ARE TO BE INPUT, GO TO 108
      IF(ISCRR-6)105,108,105
C••••••••• STORE COORDINATES OF PARALLELOPIPED CONTAINING SOURCE.
  105 COORDS(2,N)=TEMP(2)-TEMP(1)
      COORDS(1,N)=TEMP(1)
      COORDS(4,N)=TEMP(4)-TEMP(3)
      COORDS(3,N)=TEMP(3)
      COORDS(6,N)=TEMP(6)-TEMP(5)
      COORDS(5,N)=TEMP(5)
      GO TO 109
C••••••••• READ INPUT RAYS.
  108 IPOINT(N)=IP
      DO 110 I=1,ISMAXI
      READ 14,ALRAY(IP),BERAY(IP),GARAY(IP),XRAY(IP),
     *YRAY(IP),ZRAY(IP)
   14 FORMAT(17X,6F8.3)
C••••••••• CHECK DIRECTIONAL COSINES.
      CALL CHECK(6HSORDAT,ALRAY(IP ),BERAY(IP ),GARAY(IP ))
C••••••••• INCREASE POINTER BY 1.
      IP=IP+1
  110 CONTINUE
C••••••••• GO LOOK AT NEXT SOURCE DATA CARD.
  109 GO TO 112
  111 RETURN
      END
      SUBROUTINE SPHNOR(K)
C*********************************************************************
C********** SPHNOR FINDS THE DIRECTIONAL COSINES OF THE NORMAL TO
C********** A POINT ON THE SURFACE OF A SPHERE.
C*********************************************************************
      COMMON /69/      ABCO(20,200)       ,ALRAY(500)       ,BERAY(500)
     1 ,COORDS(6,50)  ,E(40,200)          ,EBASE(200)       ,ESCH(20,200)
     2 ,GARAY(500)    ,RED(20,200)        ,TITLE(12)        ,VMAT(20)
     3 ,VOL(200)      ,XLAM(200)          ,XRAY(500)        ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/  ALK(200)           ,ALPHA(40)        ,BEK(200)
     1 ,BETA(40)      ,DEV(200)           ,DK(200)          ,EK(200)
     2 ,ELAM(200)     ,ELAMAT(20)         ,EMAT(20)         ,ENERGY(200)
     3 ,GAK(200)      ,GAMMA(40)          ,REF(20)          ,SOMMAT(20)
     4 ,SUMRAY(200)   ,SUMSQR(200)        ,X(40)            ,XK(200)
     5 ,Y(40)         ,YK(200)            ,Z(40)            ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                    IFLAG(40)     ,IPOINT(50)     ,
     *ISMAX(50)     ,ISOR(20)         ,JF(200)        ,JFL(200)       ,
     *JL(200)       ,JM(200)          ,JN(200)        ,JP(200)        ,
     *JRAY(200)     ,JSOR(50)         ,KBND(900)      ,KFLAG(200)     ,
     *KP(200)       ,KTYP(200)        ,LAMP(50)       ,LANGLE(20)     ,
     *LREFL(200)    ,LTYPE(20)        ,MAT(200)       ,MFL(20)        ,
     *NMAT(20)      ,NUMRAY(200)
      COMMON/PARAMS/       AL         ,ALN       ,ALR       ,ALRF      ,BE     ,
     *BEN       ,BER       ,BERF      ,DIS       ,DMIN      ,DZ        ,EPS    ,
     *GA        ,GAN       ,GAR       ,GARF      ,PER       ,
     *SUMRA     ,XI        ,XNOW      ,XOLD      ,XREF      ,XTRAN     ,YI     ,
     *YNOW      ,YOLD      ,YREF      ,YTRAN     ,ZI        ,
     *ZNOW      ,ZOLD      ,ZREF      ,ZTRAN
      COMMON/IPARAM/       FMAX       ,IMAX      ,INOW      ,
     *IDPRAY    ,IOPRNT    ,IR        ,IRAY      ,JMAX      ,JNOW      ,JOLD   ,
     *KINT      ,KMAX      ,KNOW      ,MMAX      ,NNOW      ,NSOR
      INTEGER F,FMAX
C********** CALCULATE DIRECTIONAL COSINES.
      ALN=(XNOW-XK(K))/DK(K)
      BEN=(YNOW-YK(K))/DK(K)
      GAN=(ZNOW-ZK(K))/DK(K)
C********** CHECK DIRECTIONAL COSINES.
      CALL CHECK(6HSPHNOR,ALN,BEN,GAN)
      CALL DEBUG(6HSPHNOR)
      RETURN
      END
      SUBROUTINE SSORCE
C**********************************************************************
C********** SSORCE CREATES A RAY FOR A SURFACE SOURCE.
C**********************************************************************
      COMMON /69/         ABCO(20,200)        ,ALRAY(500)         ,BERAY(500)
     1 ,COORDS(6,50)      ,E(40,200)          ,EBASE(200)         ,ESOR(20,200)
     2 ,FARAY(500)        ,RED(20,200)        ,TITLE(12)          ,VMAT(20)
     3 ,VOL(200)          ,XLAM(200)          ,XRAY(500)          ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/     ALK(200)            ,ALPHA(40)          ,BEK(200)
     1 ,BETA(40)          ,DEV(200)           ,DK(200)            ,EK(200)
     2 ,ELAM(200)         ,ELAMAT(20)         ,EMAT(20)           ,ENERGY(200)
     3 ,GAK(200)          ,GAMMA(40)          ,REF(20)            ,SUMMAT(20)
     4 ,SUMRAY(200)       ,SUMSOR(200)        ,X(40)              ,XK(200)
     5 ,Y(40)             ,YK(200)            ,Z(40)              ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                     IFLAG(40)         ,IPOINT(50)       ,
     *,ISMAX(50)      ,ISOR(20)          ,JF(200)          ,JFL(200)         ,
     *,JL(200)        ,JM(200)           ,JN(200)          ,JP(200)          ,
     *,JRAY(200)      ,JSOR(50)          ,KBND(900)        ,KFLAG(200)       ,
     *,KP(200)        ,KTYP(200)         ,LAMP(50)         ,LANGLE(20)       ,
     *,LREFL(200)     ,LTYPE(20)         ,MAT(200)         ,MFL(20)          ,
     *,NMAT(20)       ,NUMRAY(200)
      COMMON/PARAMS/          AL          ,ALN        ,ALR        ,ALRF       ,RE      ,
     *,BEN        ,BER        ,BERF        ,DIS        ,DMIN       ,DZ         ,EPS     ,
     *,GA         ,GAN        ,GAR         ,GARF       ,PER        ,
     *,SUMRA      ,XI         ,XNOW        ,XOLD       ,XREF       ,XTRAN      ,YI      ,
     *,YNOW       ,YOLD       ,YREF        ,YTRAN      ,ZI         ,
     *,ZNOW       ,ZOLD       ,ZREF        ,ZTRAN
      COMMON/IPARAM/          FMAX        ,IMAX       ,INOW       ,
     *,IOPRAY     ,IOPRNT     ,IR          ,IRAY       ,JMAX       ,JNOW       ,JOLD    ,
     *,KINT       ,KMAX       ,KNOW        ,MMAX       ,NNOW       ,NSOR
      INTEGER F,FMAX
      DATA(TWOPI=6.283185)
      I=IMAX
C********** FIND A RANDOM POINT(X(I),Y(I),Z(I)) ON THE SURFACE
      THI=TWOPI*RAND(0)
      K=JSOR(NNOW)
      SN=EPS
      IF(ISOR(NNOW)-3)104,103,104
  103 SN=-SN
  104 CONTINUE
      X(I)=XK(K)+(DK(K)+SN)*COS(THI)
      Y(I)=YK(K)+(DK(K)+SN)*SIN(THI)
      Z(I)=COORDS(5,NNOW)+COORDS(6,NNOW)*RAND(0)
      KNOW=K
      XNOW=X(I)
      YNOW=Y(I)
      ZNOW=Z(I)
C********** FIND THE NORMAL TO THE POINT.
      CALL NORMAL
C********** GET TWO ANGLES FOR DESIRED PROBABILITY DISTRIBUTION.
      CALL ANGLES(TH,PHI)
      COSTH=COS(TH)
      COSPHI=COS(PHI)
      SINPHI=SIN(PHI)
      SINTH=SQRT(1.0-COSTH**2)
C********** CALCULATE DIRECTIONAL COSINES OF RAY.
      ALPHA(I)=ALN*COSTH+BEN*SINPHI*SINTH
      BETA(I)=BEN*COSTH-ALN*SINPHI*SINTH
      GAMMA(I)=COSPHI*SINTH

C********** IF RAY SHOULD POINT INWARDS, REVERSE DIRECTION OF RAY.
      IF(SN)101,102,102
  101 ALPHA(I)=-ALPHA(I)
      BETA(I)=-BETA(I)
      GAMMA(I)=-GAMMA(I)
  102 RETURN
      END
      SUBROUTINE STRUCT
C*********************************************************************
C********** SUBROUTINE STRUCT SETS UP THE SEGMENT STRUCTURE(HEIRARCHY).
C*********************************************************************
      COMMON /69/       ABCO(20,200)     ,ALRAY(500)       ,BERAY(500)
     1 ,COORDS(6,50)   ,E(40,200)       ,EBASE(200)       ,ESOR(20,200)
     2 ,GARAY(500)     ,RED(20,200)     ,TITLE(12)        ,VMAT(20)
     3 ,VOL(200)       ,XLAM(200)       ,XRAY(500)        ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/  ALK(200)         ,ALPHA(40)        ,BEK(200)
     1 ,BETA(40)       ,DEV(200)        ,DK(200)          ,EK(200)
     2 ,ELAM(200)      ,ELAMAT(20)      ,EMAT(20)         ,ENERGY(200)
     3 ,GAK(200)       ,GAMMA(40)       ,REF(20)          ,SORMAT(20)
     4 ,SUMRAY(200)    ,SUMSOR(200)     ,X(40)            ,XK(200)
     5 ,Y(40)          ,YK(200)         ,Z(40)            ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                   IFLAG(40)       ,IPOINT(50)      ,
     ,ISMAX(50)      ,ISOR(20)        ,JF(200)         ,JFL(200)        ,
     ,JL(200)        ,JM(200)         ,JN(200)         ,JP(200)         ,
     ,JRAY(200)      ,JSOR(50)        ,KBND(900)       ,KFLAG(200)      ,
     ,KP(200)        ,KTYP(200)       ,LAMP(50)        ,LANGLE(20)      ,
     ,LREFL(200)     ,LTYPE(20)       ,MAT(200)        ,MFL(20)         ,
     ,NMAT(20)       ,NUMRAY(200)
      COMMON/PARAMS/      AL        ,ALN       ,ALR       ,ALRF      ,BE        ,
     ,BEN       ,BER       ,BERF      ,DIS       ,DMIN      ,DZ        ,EPS       ,
     ,GA        ,GAN       ,GAR       ,GARF      ,PER       ,
     ,SUMRA     ,XI        ,XNOW      ,XOLD      ,XREF      ,XTRAN     ,YI        ,
     ,YNOW      ,YOLD      ,YREF      ,YTRAN     ,ZI        ,
     ,ZNOW      ,ZOLD      ,ZREF      ,ZTRAN
      COMMON/IPARAM/      FMAX      ,IMAX    - ,INOW      ,
     ,IOPRAY    ,IOPRNT    ,IR        ,IRAY      ,JMAX      ,JNOW      ,JOLD      ,
     ,KINT      ,KMAX      ,KNOW      ,MMAX      ,MNOW      ,NSOR
      INTEGER F,FMAX
      DIMENSION JDAU(22)
      PRINT 9
    9 FORMAT(1H1,53X,14HSTRUCTURE DATA//8H  MOTHER,10X,
     ,17HDAUGHTER SEGMENTS,34X/
     ,8H SEGMENT/)
      NERS=0
C********** READ ONE MOTHER AND ITS DAUGHTERS.
  120 READ 10,MOM,(JDAU(L),L=1,17)
   10 FORMAT(18I4)
C********** ZERO MOTHER SEGMENT INDICATES END OF DATA.
      IF(MOM)122,122,121
C********** COUNT NUMBER OF DAUGHTERS.
  121 DO 102 LL=1,17
      L=LL
      IF(JDAU(LL))101,101,102
  102 CONTINUE
  101 L2=L-1
C********** PRINT MOTHER AND DAUGHTERS.
      PRINT 11,MOM,(JDAU(L),L=1,L2)
   11 FORMAT(1H ,I7,5X,17I6)
      LL=1
      J=0
C********** ERROR IF MOTHER HAS NO DAUGHTERS.
      IF(JDAU(LL))103,103,104
  103 PRINT 12,JDAU(LL)
   12 FORMAT(1H ,14HMOTHER SEGMENT,I4,17H HAS NO DAUGHTERS)
      NERS=NERS+1
      GO TO 110
```

```
C********** SET VALUES FOR ARRAYS.
  104 JF(MOM)=JDAU(LL)
  105 IF(JDAU(LL))109,109,106
  106 JM1=J
      J=JDAU(LL)
      JP(J)=JM1
C********** ERROR IF SEGMENT APPEARED AS DAUGHTER ON TWO CARDS.
      IF(JM(J))108,108,107
  107 PRINT 13,J
   13 FORMAT(1H ,7HSEGMENT,I4,33H APPEARS AS DAUGHTER ON TWO CARDS)
      NERS=NERS+1
      LL=LL+1
      GO TO 105
C********** SET MOTHER OF SEGMENT J.
  108 JM(J)=MOM
      LL=LL+1
      GO TO 105
C********** SET LAST DAUGHTER OF SEGMENT.
  109 JL(MOM)=J
      LL=LL-1
  111 LL=LL-1
      IF(LL) 110,110,112
  112 JP1=J
      J=JDAU(LL)
C********** SET NEXT DAUGHTER IN HEIRARCHY.
      JN(J)=JP1
      GO TO 111
  110 GO TO 120
  122 CONTINUE
C********** CHECK TO SEE IF ANY SEGMENT HAS NO MOTHER.
      DO 116 J=2,JMAX
  113 IF(JF(J))116,116,114
  114 IF(JM(J))115,115,116
  115 PRINT 14,
   14 FORMAT(15H MOTHER SEGMENT,I4,14H HAS NO MOTHER)
      NERS=NERS+1
  116 CONTINUE
  117 IF(NERS)119,119,118
  118 PRINT 15,NERS
   15 FORMAT(1H ,I3,33H ERRORS IN SEGMENT STRUCTURE DATA)
      STOP
  119 RETURN
      END
      SUBROUTINE TABREF(LL)
      COMMON /69/        ABCO(20,200)      ,ALRAY(500)       ,BERAY(500)
     1 ,COORDS(6,50)    ,E(40,200)        ,EBASE(200)       ,ESOR(20,200)
     2 ,GARAY(500)      ,RED(20,200)      ,TITLE(12)        ,VMAT(20)
     3 ,VOL(200)        ,XLAM(200)        ,XRAY(500)        ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/    ALK(200)          ,ALPHA(40)        ,BEK(200)
     1 ,BETA(40)        ,DEV(200)         ,DK(200)          ,EK(200)
     2 ,ELAM(200)       ,ELAMAT(20)       ,EMAT(20)         ,ENERGY(200)
     3 ,GAK(200)        ,GAMMA(40)        ,REF(20)          ,SURMAT(20)
     4 ,SIMRAY(200)     ,SUMSOR(200)      ,X(40)            ,XK(200)
     5 ,Y(40)           ,YK(200)          ,Z(40)            ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                       IFLAG(40)       ,IPOINT(50)     ,
     ,ISMAX(50)       ,ISOR(20)          ,JF(200)         ,JFL(200)       ,
     ,JL(200)         ,JM(200)           ,JN(200)         ,JP(200)        ,
     ,JRAY(200)       ,JSOR(50)          ,KBND(900)       ,KFLAG(200)     ,
     ,KP(200)         ,KTYP(200)         ,LAMP(50)        ,LANGLE(20)     ,
     ,LREFL(200)      ,LTYPE(20)         ,MAT(200)        ,MFL(20)        ,
     ,NMAT(20)        ,NUMRAY(200)
      COMMON/PARAMS/           AL         ,ALN        ,ALR        ,ALRF       ,BE         ,
     ,BEN        ,BER        ,BERF       ,DIS        ,DMIN       ,DZ         ,EPS        ,
     ,GA         ,GAN        ,GAN        ,GANF       ,PER        ,
     ,SUMRA      ,XI         ,XNOW       ,XOLD       ,XREF       ,XTRAN      ,YI         ,
     ,YNOW       ,YOLD       ,YREF       ,YTRAN      ,ZI         ,
     ,ZNOW       ,ZOLD       ,ZREF       ,ZTRAN
      COMMON/IPARAM/           FMAX       ,IMAX       ,INOW       ,
     ,IOPRAY     ,ICPRNT     ,IR         ,IRAY       ,JMAX       ,JNOW       ,JOLD       ,
     ,KINT       ,KMAX       ,KNOW       ,MMAX       ,NNOW       ,NSOR
      INTEGER F,FMAX
      DIMENSION ANGLE(10)
      DATA(ANGLE=1.0,.98481,.93969,.86603,.76604,
     ,.64279,.5,.34202,.17365,0.0)
C********** CALCULATE COSINE OF ANGLE OF INCIDENCE.
      COSTH=AL*ALN+BE*BEN+GA*GAN
      COSTH=ABS(COSTH)
C********** FIND POSITION IN TABLE.
      DO 100 I=1,10
      IF(COSTH-ANGLE(I))100,101,101
  100 CONTINUE
C********** INTERPOLATE FOR PERCENT TRANSMITTED.
  101 PER=1.0-(RED(LL,I-1)+(RED(LL,I)-RED(LL,I-1))
     **(COSTH-ANGLE(I-1))/(ANGLE(I)-ANGLE(I-1)))
      RETURN
      END
      SUBROUTINE TEST
C.....................................................................
C.......... TEST READS CARDS CONTAINING TEST POINTS FOR CHECKING THE
C.......... INPUT GEOMETRIES FOR ERRORS
C.....................................................................
      COMMON /69/        ABCO(20.200)       .ALRAY(500)        .BERAY(500)
     1 .COORDS(6.50)     .E(40.200)         .EBASE(200)        .ESOR(20.200)
     2 .GARAY(500)       .RED(20.200)       .TITLE(12)         .VMAT(20)
     3 .VOL(200)         .XLAM(200)         .XRAY(500)         .YRAY(500)
     4 .ZRAY(500)
      COMMON /ARRAYS/    ALK(200)           .ALPHA(40)         .BEK(200)
     1 .BETA(40)         .DEV(200)          .DK(200)           .EK(200)
     2 .ELAM(200)        .ELAMAT(20)        .EMAT(20)          .ENERGY(200)
     3 .GAK(200)         .GAMMA(40)         .REF(20)           .SORMAT(20)
     4 .SUMRAY(200)      .SUMSQR(200)       .X(40)             .XK(200)
     5 .Y(40)            .YK(200)           .Z(40)             .ZK(200)
     6 .ZLAM(20)
      COMMON/IARRAY/                     IFLAG(40)        .IPOINT(50)      .
     .ISMAX(50)        .ISOR(20)         .JF(200)         .JFL(200)        .
     .JL(200)          .JM(200)          .JN(200)         .JP(200)         .
     .JRAY(200)        .JSOR(50)         .KBND(900)       .KFLAG(200)      .
     .KP(200)          .KTYP(200)        .LAMP(50)        .LANGLE(20)      .
     .LREFL(200)       .LTYPE(20)        .MAT(200)        .MFL(20)         .
     .NMAT(20)         .NUMRAY(200)
      COMMON/PARAMS/       AL         .ALN        .ALR        .ALRF       .BE      .
     .BEN       .BER       .BERF       .DIS        .DMIN       .DZ         .EPS     .
     .GA        .GAN       .GAR        .GARF       .PER        .
     .SUMRA     .XI        .XNOW       .XOLD       .XREF       .XTRAN      .YI      .
     .YNOW      .YOLD      .YREF       .YTRAN      .ZI         .
     .ZNOW      .ZOLD      .ZREF       .ZTRAN
      COMMON/IPARAM/       FMAX       .IMAX       .INCH       .
     .IOPRAY    .IOPRNT    .IR         .IRAY       .JMAX       .JNOW       .JOLD    .
     .KINT      .KMAX      .KNOW       .MMAX       .NNOW       .NSOR
      INTEGER F.FMAX
      PRINT 12
   12 FORMAT(1H1.53X.9HTEST DATA//1H .7HSEGMENT.2H  OPTION.
     .11X.1HX.11X.1HY.11X.1HZ/)
      ISTOP=0
C.......... READ A CARD
  112 READ 10.JTEST.IOP.XI.YI.ZI
   10 FORMAT(2I6.3E12.4)
C.......... ZERO JTEST INDICATES END OF DATA.
      IF(JTEST)100.110.100
C.......... SET PRESENT SEGMENT NUMBER.
  100 JNOW=IABS(JTEST)
      PRINT 13.JTEST.IOP.XI.YI.ZI
   13 FORMAT(1H .I7.2X.I6.3E12.4)
C.......... FOR IOP=0. TEST SEGMENT BOUNDARIES ONLY
C.......... FOR IOP=1. TEST TO SEE IF POINT IS INSIDE SEGMENT.
      IF(IOP)101.102.101
C.......... FIND SEGMENT CONTAINING POINT
  101 CALL SEGMNT
      GO TO 105
C.......... SEE IF POINT IS INSIDE OF THE BOUNDARIES OF JNOW.
  102 IF(INSEG(JNOW))104.103.104
C.......... POINT NOT INSIDE SEGMENT JNOW
  103 JNOW=0
      GO TO 105
C.......... POINT IS INSIDE SEGMENT JNOW
  104 JNOW=IABS(JTEST)
C.......... IF POINT IS IN SEGMENT JTEST. GO TO 106
```

```
  105 IF(JNOW-IABS(JTEST))107,106,107
C********* SEE IF DESIRED RESULT WAS OBTAINED.
  106 IF(JTEST)109,108,108
  107 IF(JTEST)108,109,109
  108 IERR=0
      GO TO 111
  109 IERR=1
C********* DID AN ERROR OCCUR.
  111 IF(IERR)112,112,113
  113 ISTOP=1
      CALL SEGMNT
      PRINT 11,JNOW
   11 FORMAT(10X,24HABOVE TEST POINT IN SEG ,I4,14H - RUN ABORTED/)
      GO TO 112
C********* IF ERRORS OCCURRED, STOP
  110 IF(ISTOP)115,115,114
  114 STOP
  115 RETURN
      END
      SUBROUTINE THOFS
C**********************************************************************
C********** THOFS CALCULATES TH AS A FUNCTION OF STH.
C********** PART OF HELIX INTERSECTION CALCULATION.
C**********************************************************************
      COMMON /69/        ABCO(20,200)      ,ALRAY(500)      ,BERAY(500)
     1 ,COORDS(6,50)  ,E(40,200)         ,EBASE(200)      ,ESOR(20,200)
     2 ,GARAY(500)    ,RED(20,200)       ,TITLE(12)       ,VMAT(20)
     3 ,VOL(200)      ,XLAM(200)         ,XRAY(500)       ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/  ALK(200)          ,ALPHA(40)       ,BEK(200)
     1 ,BETA(40)      ,DEV(200)          ,DK(200)         ,EK(200)
     2 ,FLAM(200)     ,ELAMAT(20)        ,EMAT(20)        ,ENERGY(200)
     3 ,GAK(200)      ,GAMMA(40)         ,REF(20)         ,SCHMAT(20)
     4 ,SUMRAY(200)   ,SUMSOR(200)       ,X(40)           ,XK(200)
     5 ,Y(40)         ,YK(200)           ,Z(40)           ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                  IFLAG(40)      ,IPOINT(50)     ,
     ,ISMAX(50)     ,ISOR(20)         ,JF(200)       ,JFL(200)       ,
     ,JL(200)       ,JM(200)          ,JN(200)       ,JP(200)        ,
     ,JRAY(200)     ,JSOR(50)         ,KBND(900)     ,KFLAG(200)     ,
     ,KP(200)       ,KTYP(200)        ,LAMP(50)      ,LANGLE(20)     ,
     ,LREFL(200)    ,LTYPE(20)        ,MAT(200)      ,MFL(20)        ,
     ,NMAT(20)      ,NUMRAY(200)
      COMMON/PARAMS/        AL         ,ALN      ,ALR      ,ALRF     ,BE     ,
     ,BEN      ,BER      ,BERF       ,DIS      ,DMIN     ,DZ       ,EPS    ,
     ,GA       ,GAN      ,GAR        ,GARF     ,PER      ,
     ,SUMRA    ,XI       ,XNOW       ,XOLD     ,XREF     ,XTRAN    ,YI     ,
     ,YNOW     ,YOLD     ,YREF       ,YTRAN    ,ZI       ,
     ,ZNOW     ,ZOLD     ,ZREF       ,ZTRAN    -
      COMMON/IPARAM/        FMAX       ,IMAX     ,INOW     ,
     ,IOPRAY   ,IOPRNT   ,IR         ,IRAY     ,JMAX     ,JNOW     ,JOLD   ,
     ,KINT     ,KMAX     ,KNOW       ,MMAX     ,NNOW     ,NSOR
      INTEGER F,FMAX
      COMMON/HELCOM/A,ABAR,B,B1,B1P,BP,CAP,DELTH,DELX,DELY,DELZ,DMIT,
     ,PSIZ,REV,RND,STH,TH,TH1,SORKS,RKS,CSTH,SNTH,RCSTH,RSNTH,BSTH,
     ,COSTAN,THZ,DTHZ
C********** CALCULATE PARAMETERS NEEDED.
      THV=TH
1                 CONTINUE
      DZTH=GA*STH-DELZ-CAP*TH
      DXTH=AL*STH-DELX
      DYTH=BE*STH-DELY
      FT=RSNTH*DXTH-RCSTH*DYTH-CAP*DZTH
      FP=RCSTH*DXTH+RSNTH*DYTH+CAP**2
      IF(FP.GT.0.) GO TO 2
      FINT=.5*(DXTH**2+DYTH**2+DZTH**2)
      FTP=FINT/FT
      GO TO 3
2                 CONTINUE
      FTP=FT/FP
3                 CONTINUE
      IF(ABS(FTP).GT.1) GO TO 4
C********** CALCULATE TH
      TH=TH-FTP
C********** CALCULATE COSTAN.
      CALL CCSTAN
C********** SEE IF MORE ITERATIONS ARE NEEDED.
      IF(ABS(FTP).GT..001) GO TO 1
      DELTH=TH-THV
      RETURN

4                 CONTINUE
      DELTH=SIGN(1.,FTP)
      TH=TH-DELTH
      CALL CCSTAN
      RETURN
      END
      SUBROUTINE VSORCE
      COMMON /69/        ABCO(20,200)       ,ALRAY(500)       ,BERAY(500)
     1 ,COORDS(6,50)   ,E(40,200)          ,EBASE(200)       ,ESOM(20,200)
     2 ,GARAY(500)     ,RED(20,200)        ,TITLE(12)        ,VMAT(20)
     3 ,VOL(200)       ,XLAM(200)          ,XRAY(500)        ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/  ALK(200)            ,ALPHA(40)        ,BEK(200)
     1 ,BETA(40)       ,DEV(200)           ,DK(200)          ,EK(200)
     2 ,ELAM(200)      ,ELAMAT(20)         ,EMAT(20)         ,ENERGY(200)
     3 ,GAK(200)       ,GAMMA(40)          ,REF(20)          ,SCRMAT(20)
     4 ,SUMRAY(200)    ,SUMSCR(200)        ,X(40)            ,XK(200)
     5 ,Y(40)          ,YK(200)            ,Z(40)            ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                    IFLAG(40)        ,IPOINT(50)       ,
     *ISMAX(50)       ,ISOR(20)         ,JF(200)          ,JFL(200)         ,
     *JL(200)         ,JM(200)          ,JN(200)          ,JP(200)          ,
     *JRAY(200)       ,JSOR(50)         ,KBND(900)        ,KFLAG(200)       ,
     *KP(200)         ,KTYP(200)        ,LAMP(50)         ,LANGLE(20)       ,
     *LREFL(200)      ,LTYPE(20)        ,MAT(200)         ,MFL(20)          ,
     *NMAT(20)        ,NUMRAY(200)
      COMMON/PARAMS/       AL         ,ALN        ,ALR        ,ALRF       ,RE         ,
     *BEN       ,BER       ,BERF       ,DIS        ,DMIN       ,DZ         ,EPS        ,
     *GA        ,GAN       ,GAR        ,GARF       ,PER        ,
     *SUMRA     ,XI        ,XNOW       ,XOLD       ,XREF       ,XTRAN      ,YI         ,
     *YNOW      ,YOLD      ,YREF       ,YTRAN      ,ZI         ,
     *ZNOW      ,ZOLD      ,ZREF       ,ZTRAN
      COMMON/IPARAM/       FMAX       ,IMAX       ,INOW       ,
     *IOPRAY    ,IOPRNT    ,IR         ,IRAY       ,JMAX       ,JNOW       ,JOLD       ,
     *KINT      ,KMAX      ,KNOW       ,MMAX       ,NNOW       ,NSOR
      INTFGER F,FMAX
C********** CALCULATE COORDINATES OF A POINT WITHIN SOURCE LIMITS.
  102 XI=COORDS(1,NNOW)+RAND(0)*COORDS(2,NNOW)
      YI=COORDS(3,NNOW)+RAND(0)*COORDS(4,NNOW)
      ZI=COORDS(5,NNOW)+RAND(0)*COORDS(6,NNOW)
      J=JSOR(NNOW)
C********** SEE IF POINT LIES WITHIN SOURCE SEGMENT.
      JNOW=I
      CALL SEGMNT
      IF(J-JNOW)102,103,102
C********** CALCULATE RANDOM COMPONENTS OF A VECTOR.
  103 DELX=2.0*RAND(0)-1.0
      DELY=2.0*RAND(0)-1.0
      DELZ=2.0*RAND(0)-1.0
C********** CALCULATE LENGTH OF VECTOR.
      R=SQRT(DELX**2+DELY**2+DELZ**2)
C********** IF VECTOR LENGTH GREATER THAN 1.0, GO CREATE ANOTHER VECTOR.
      IF(R-1.0)104,104,103
C********** CALCULATE DIRECTIONAL COSINES OF RAY.
  104 ALPHA(IMAX)=DELX/R
      BETA(IMAX)=DELY/R
      GAMMA(IMAX)=DELZ/R
C********** STORE COORDINATES OF RAY.
      X(IMAX)=XI
      Y(IMAX)=YI
      Z(IMAX)=ZI
      RETURN
      END
      SUBROUTINE WAVREF(LL)
C************************************************************************
C********* WAVREF CALLS THE DESIRED ROUTINE TO PROVIDE REFLECTION
C********* FRACTIONS AS A FUNCTION OF WAVELENGTH AND ANGLE
C********* OF INCIDENCE.
C************************************************************************
      COMMON /69/        ABCO(20,200)     ,ALRAY(500)      ,BERAY(500)
     1 ,COORDS(6,50)    ,E(40,200)       ,EBASE(200)      ,ESOM(20,200)
     2 ,GARAY(500)      ,RED(20,200)     ,TITLE(12)       ,VMAT(20)
     3 ,VOL(200)        ,XLAM(200)       ,XRAY(500)       ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/    ALK(200)         ,ALPHA(40)       ,BEK(200)
     1 ,BETA(40)        ,DEV(200)        ,DK(200)         ,EK(200)
     2 ,ELAM(200)       ,ELAMAT(20)      ,EMAT(20)        ,ENERGY(200)
     3 ,GAK(200)        ,GAMMA(40)       ,REF(20)         ,SOMMAT(20)
     4 ,SUMRAY(200)     ,SUMSOR(200)     ,X(40)           ,XK(200)
     5 ,Y(40)           ,YK(200)         ,Z(40)           ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                   IFLAG(40)      ,IPOINT(50)     ,
     ,ISMAX(50)      ,ISOR(20)         ,JF(200)       ,JFL(200)       ,
     ,JL(200)        ,JM(200)          ,JN(200)       ,JP(200)        ,
     ,JRAY(200)      ,JSOR(50)         ,KBND(900)     ,KFLAG(200)     ,
     ,KP(200)        ,KTYP(200)        ,LAMP(50)      ,LANGLE(20)     ,
     ,LREFL(200)     ,LTYPE(20)        ,MAT(200)      ,MFL(20)        ,
     ,NMAT(20)       ,NUMRAY(200)
      COMMON/PARAMS/          AL         ,ALN        ,ALR        ,ALRF       ,BE     ,
     ,BEN        ,BER        ,BERF       ,DIS        ,DMIN       ,DZ         ,EPS    ,
     ,GA         ,GAN        ,GAR        ,GARF       ,PER        ,
     ,SUMRA      ,XI         ,XNOW       ,XOLD       ,XREF       ,XTRAN      ,YI     ,
     ,YNOW       ,YOLD       ,YREF       ,YTRAN      ,ZI         ,
     ,ZNOW       ,ZOLD       ,ZREF       ,ZTRAN
      COMMON/IPARAM/          FMAX       ,IMAX       ,INOW       ,
     ,IOPRAY     ,IOPRNT     ,IR         ,IRAY       ,JMAX       ,JNOW       ,JOLD   ,
     ,KINT       ,KMAX       ,KNOW       ,NMAX       ,NNOW       ,NSOR
      INTEGER F,FMAX
      DIMENSION TSTG(200)
      COSGAM=AL*ALN+BE*BEN+GA*GAN
      GO TO(100,200,300,400,500,600,700,800,900),LL
  100 CALL REFL11(XLAM,FMAX,TSTG       ,COSGAM)
      GO TO 110
  200 CALL REFL12(XLAM,FMAX,TSTG       ,COSGAM)
      GO TO 110
  300 CALL REFL13(XLAM,FMAX,TSTG       ,COSGAM)
      GO TO 110
  400 CALL REFL14(XLAM,FMAX,TSTG       ,COSGAM)
      GO TO 110
  500 CALL REFL15(XLAM,FMAX,TSTG       ,COSGAM)
      GO TO 110
  600 CALL REFL16(XLAM,FMAX,TSTG       ,COSGAM)
      GO TO 110
  700 CALL REFL17(XLAM,FMAX,TSTG       ,COSGAM)
      GO TO 110
  800 CALL REFL18(XLAM,FMAX,TSTG       ,COSGAM)
      GO TO 110
  900 CALL REFL19(XLAM,FMAX,TSTG       ,COSGAM)
C********* STORE WAVELENGTH DEPENDENT FRACTIONS OF REFLECTION
  110 DO 101 F=1,FMAX
      RED(LL,F)=TSTG(F)
  101 CONTINUE
      RETURN
      END
```

```
                         SUBROUTINE ZCALC
C***********************************************************************
C********** ZCALC HANDLES CASES WHERE COSTAN IS LARGE.
C********** PART OF HELIX INTERSECTION CALCULATION.
C***********************************************************************
      COMMON /69/        ABCD(20,200)       ,ALRAY(500)        ,BERAY(500)
     1 ,COORDS(6,50)    ,E(40,200)          ,EBASE(200)        ,ESUR(20,200)
     2  FARAY(500)      ,RED(20,200)        ,TITLE(12)         ,VMAT(20)
     3  VOL(200)        ,XLAM(200)          ,XRAY(500)         ,YRAY(500)
     4 ,ZRAY(500)
      COMMON /ARRAYS/    ALK(200)           ,ALPHA(40)         ,BEK(200)
     1 ,BETA(40)        ,DEV(200)           ,DK(200)           ,EK(200)
     2 ,FLAM(200)       ,ELAMAT(20)         ,EMAT(20)          ,ENERGY(200)
     3 ,GAK(200)        ,GAMMA(40)          ,REF(20)           ,SGMAT(20)
     4 ,SUMRAY(200)     ,SUMSQR(200)        ,X(40)             ,XK(200)
     5 ,Y(40)           ,YK(200)            ,Z(40)             ,ZK(200)
     6 ,ZLAM(20)
      COMMON/IARRAY/                     IFLAG(40)        ,IPOINT(50)      ,
     ,ISMAX(50)        ,ISOR(20)         ,JF(200)          ,JFL(200)        ,
     ,JL(200)          ,JM(200)          ,JN(200)          ,JP(200)         ,
     ,JRAY(200)        ,JSCR(50)         ,KBND(960)        ,KFLAG(200)      ,
     ,KP(200)          ,KTYP(200)        ,LAMP(50)         ,LANGLE(20)      ,
     ,LREFL(200)       ,LTYPE(20)        ,MAT(200)         ,MFL(20)         ,
     ,NMAT(20)         ,NUMRAY(200)
      COMMON/PARAMS/               AL         ,ALN        ,ALR        ,ALRF       ,RE     ,
     ,BEN        ,BER        ,BERF       ,DIS        ,DMIN       ,DZ         ,EPS    ,
     ,GA         ,GAN        ,GAR        ,GAMF       ,PER        ,
     ,SUMRA      ,XI         ,XNOW       ,XOLD       ,XREF       ,XTRAN      ,YI     ,
     ,YNOW       ,YOLD       ,YREF       ,YTRAN      ,Z1         ,
     ,ZNOW       ,ZOLD       ,ZREF       ,ZTRAN
      COMMON/IPARAM/               FMAX       ,IMAX       ,INOW       ,
     ,ICPRAY     ,IOPRNT     ,IR         ,IRAY       ,JMAX       ,JNOW       ,JOLD   ,
     ,KINT       ,KMAX       ,KNOW       ,MMAX       ,MNOW       ,NSOR
      INTEGER F,FMAX
      COMMON/HELCOM/A,ABAR,B,BI,BIP,BP,CAP,DELTH,DELX,DELY,DELZ,DHIT,
     ,PSIZ,REV,RHO,STH,TH,THI,SQRKS,RKS,CSTH,SNTH,RCSTH,RSNTH,BSTH,
     ,COSTAN,THZ,DTHZ
      DATA(MSTIR=4)
C********** CALCULATE PARAMETERS.
      XII=CAP*GA/(RHO*(AL*SIN(THZ)-BE*COS(THZ)))
C********** SEE IF RAY IS EVER PARALLEL TO PLANE PERPINDICULAR TO TANGENT
      IF(XII-1.0)101,102,102
  101 IF(XII-COS(2.6))102,102,103
C********** RAY IS NEVER PARALLEL.
102              CONTINUE
      DELTH=DTHZ*.5
      TH=THZ
      GO TO 109
  103 ZETA=ACOS(XII)
      ZETA=SIGN(ZETA,DTHZ)
C********** CALCULATE ANGLE WHERE PLANE IS PARALLEL.
  104 THP=THZ+ZETA
C********** CALCULATE DISTANCE FROM RAY TO PARALLEL PLANE.
      DPERP=(DELX*RHO*SIN(THP)-DELY*RHO*COS(THP)
     **CAP*(-DELZ-CAP*THP))/SQRKS
  106 DTHMIN=DPERP*SQRKS/(RKS+1.2*A*RHO)
      THMAX=THZ+ZETA+DTHMIN
C********** CALCULATE ANGLE FOR STARTING SEARCH.
      TH=THZ
      IF(DPERP*ZETA)108,108,107
107   TH=SIGN(2.6,ZETA)+THZ
```

```
C.......... CALCULATE AMOUNT OF ANGLE FOR EACH STEP IN SEARCH.
  108 DELTM=(TMMAX-TM)/MSTAR
C.......... CALCULATE B AND BP.
  109 CALL BCALC
      BZ=B
      BZP=BP
C.......... LOOK FOR INTERSECTION.
      CALL DSUB(MSTAR)
      IF(BZ.GT.ABAR) RETURN
      TM=TMZ
      B=BZ
      BP=BZP
      DELTM=-DELTM
      CALL DSUB(MSTAR)
  110 RETURN
      END
```

```
SUBROUTINE ANGLE1(TH,PHI)
I=1
RETURN
END
```

```
SUBROUTINE REFL11(XLAM,FMAX,ISTS,COSGAM)
I=1
RETURN
END
```

```
SUBROUTINE INTEN1(XLAM,FMAX,ISIG,LT)
I=1
RETURN
END
```

```
SUBROUTINE ABS1(XLAM,FMAX,TSIG,M)
I=1
RETURN
END
```

```
SUBROUTINE ANGLEZ(TH,PHI)
I=1
RETURN
END
```

```
SUBROUTINE REFL12(XLAM,FMAX,ISTG,LCOGAM)
I=1
RETURN
END
```

```
SUBROUTINE INTEN2(XLAM,FMAX,ISIG,LT)
I=1
RETURN
END
```

```
SUBROUTINE ABS2(XLAM,FMAX,TSIG,M)
I=1
RETURN
END
```

```
SUBROUTINE ANGLE3(TH,PHI)
I=1
RETURN
END
```

```
SUBROUTINE REFL13(XLAM,FMAX,ISTG,COSGAM)
I=1
RETURN
END
```

```
SUBROUTINE INTEN3(XLAM,FMAX,ISTG,LT)
I=1
RETURN
END
```

```
SUBROUTINE ABS3(XLAM,FMAX,ISIG,M)
I=1
RETURN
END
```

```
SUBROUTINE ANGLE4(TH,PHI)
I=1
RETURN
END
```

```
SUBROUTINE REFL14(XLAM,FMAX,ISTG,COSGAM)
I=1
RETURN
END
```

```
SUBROUTINE INTENS(XLAM,FMAX,ISTG,LT)
I=1
RETURN
END
```

```
SUBROUTINE ABS4(XLAM,FMAX,TSIG,M)
I=1
RETURN
END
```

```
SUBROUTINE ANGLES(TH,PHI)
I=1
RETURN
END
```

```
SUBROUTINE REFL15(XLAM,FMAX,ISTG,COSGAM)
I=1
RETURN
END
```

```
SUBROUTINE INTENS(XLAM,FMAX,TSIG,LT)
I=1
RETURN
END
```

```
SUBROUTINE ABSS(XLAM,FMAX,TSIG,N)
I=1
RETURN
END
```

```
SUBROUTINE ANGLE6(TH,PHI)
I=1
RETURN
END
```

```
SUBROUTINE REFL16(XLAM,FMAX,ISTG,COSGAM)
I=1
RETURN
END
```

```
SUBROUTINE INTEMG(XLAM,FMAX,TSTG,LT)
I=1
RETURN
END
```

```
SUBROUTINE ABS6(XLAM,FMAX,TSTG,N)
I=1
RETURN
END
```

```
SUBROUTINE ANGLE7(TH,PHI)
I=1
RETURN
END
```

```
SUBROUTINE REFL17(XLAM,FMAX,ISTS,COSGAM)
I=1
RETURN
END
```

```
SUBROUTINE INTEXT(XLAM,FMAX,ISTG,LT)
I=1
RETURN
END
```

```
SUBROUTINE ABST(XLAM,FMAX,TST0,M)
I=1
RETURN
END
```

```
SUBROUTINE ANGLE3(TH,PHI)
I=1
RETURN
END
```

```
SUBROUTINE REFL18(XLAM,FMAX,ISTG,COSGAM)
I=1
RETURN
END
```

```
SUBROUTINE INTEMB(XLAM,FMAX,ISIG,LT)
I=1
RETURN
END
```

```
SUBROUTINE ABS8(XLAM,FMAX,TSIG,N)
I=1
RETURN
END
```

```
SUBROUTINE ANGLE9(TH,PHI)
I=1
RETURN
END
```

```
SUBROUTINE REFL19(XLAM,FMAX,ISTG,COSGAM)
I=1
RETURN
END
```

```
SUBROUTINE INTEN9(XLAM,FMAX,ISTG,LT)
I=1
RETURN
END
```

```
SUBROUTINE ABS9(XLAM,FMAX,TSIG,M)
I=1
RETURN
END
```

APPENDIX D

ZAP DATA SHEETS

PREPARED FOR NRL BY
SYSTEMS, SCIENCE AND SOFTWARE

REFLECTION DATA SHEET FOR ZAP

1–10 | 11–20 | 21–30 | 31–40 | 41–50 | 51–60 | 61–70 | 71–80

1234567890 1234567890 1234567890 1234567890 1234567890 1234567890 1234567890 1234567890

REFL. NO.	REFL. TYPE	PARAMETERS DESCRIBING REFLECTION										I.D. SEQUENCE

PREPARED FOR NRL BY
SYSTEMS, SCIENCE AND SOFTWARE

MATERIAL DATA SHEET FOR ZAP

1–10		11–20	21–30		31–40	41–50	51–60	61–70	71–80
MAT NO.	ABSORB ROUTINE	ABSORB COEFF	REFRAC INDEX	LASING WAVE LENGTH	COMMENTS				I.D. SEQUENCE

PREPARED FOR NRL BY

SYSTEMS, SCIENCE AND SOFTWARE

BOUNDARY DATA SHEET FOR ZAP

1–10		11–20		21–30		31–40		41–50		51–60		61–70		71–80
BND NO	REFL TYPE	BND TYPE	PARAMETERS DESCRIBING GEOMETRY											ID SEQUENCE

PREPARED FOR NRL BY
SYSTEMS, SCIENCE AND SOFTWARE

SEGMENT DATA SHEET FOR ZAP

1–10 | 11–20 | 21–30 | 31–40 | 41–50 | 51–60 | 61–70 | 71–80

1234567890 1234567890 1234567890 1234567890 1234567890 1234567890 1234567890 1234567890

SEG NO	MAT NO	± BND	± BND	± BND	± BND	± BND	± BND	± BND	± BND	± BND	± BND	± BND	VOLUME	I.D. SEQUENCE

PREPARED FOR NRL BY

SYSTEMS, SCIENCE AND SOFTWARE

STRUCTURE DATA SHEET FOR ZAP

1–10	11–20	21–30	31–40	41–50	51–60	61–70	71–80
1 2 3 4 5 6 7 8 9 0	1 2 3 4 5 6 7 8 9 0	1 2 3 4 5 6 7 8 9 0	1 2 3 4 5 6 7 8 9 0	1 2 3 4 5 6 7 8 9 0	1 2 3 4 5 6 7 8 9 0	1 2 3 4 5 6 7 8 9 0	1 2 3 4 5 6 7 8 9 0

MOT SEG	DAUGHTER SEGMENTS	I.D. SEQUENCE

PREPARED FOR NRL BY
SYSTEMS, SCIENCE AND SOFTWARE

LAMP DATA SHEET FOR ZAP

1–10		11–20	21–30	31–40	41–50 51–60 61–70	71–80
LAMP NO.	SOURCE TYPE	INTEN ROUTINE	ANGLE ROUTINE	INTENSITY		I.D. SEQUENCE

PREPARED FOR NRL BY
SYSTEMS, SCIENCE AND SOFTWARE

SOURCE DATA SHEET FOR ZAP

1–10 | 11–20 | 21–30 | 31–40 | 41–50 | 51–60 | 61–70 | 71–80

1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0

SOU NO.	SEG OR BND	LAM NO	NO. OF RAYS	XMIN	XMAX	YMIN	YMAX	ZMIN	ZMAX		I.D. SEQUENCE

PREPARED FOR NRL BY
SYSTEMS, SCIENCE AND SOFTWARE

TEST DATA SHEET FOR ZAP

1–10 | 11–20 | 21–30 | 31–40 | 41–50 | 51–60 | 61–70 | 71–80

1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0

SEG. NO.	OPTION	X	Y	Z		I.D. SEQUENCE

PREPARED FOR NRL BY
SYSTEMS, SCIENCE AND SOFTWARE

PLOT DATA SHEET FOR ZAP

1–10		11–20		21–30		31–40		41–50		51–60		61–70		71–80	
1234567890		1234567890		1234567890		1234567890		1234567890		1234567890		1234567890		1234567890	

X0	Y0	Z0	X1	Y1	Z1	X2	Y2	Z2	I.D. SEQUENCE